Merced River
Gravel Augmentation Project

Monitoring Report

California Department of Water Resources
San Joaquin District
River Management section

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Report Prepared by:

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(Four-Pumps)

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TABLE OF CONTENTS

FIGURES

TABLES

INTRODUCTION

Dams have created physical barriers that limit or eliminate natural gravel recruitment in the lower reaches of controlled rivers. Other human impacts have also contributed to the decline of rivers by competing with other species for valuable resources. In-channel gravel mining has been one of the greatest historical factors that lead to channel degradation. Deep pools, trapped sediment, and potential habitat for predatory fish all contribute to the decline in salmon habitat. In order to compensate for this, gravel replenishment over the years has provided the Merced River system, and the Merced River Hatchery Site in particular, with suitable spawning and rearing habitat. Although this may not serve as a long term solution due to economic constraints, it does provide the necessary habitat salmon need to proliferate in the river's current regime.

Site Description

The Merced River Gravel Augmentation Project, also known as the Merced River Hatchery Site, is located on the Merced River immediately downstream of the Crocker-Huffman Dam at approximately River Mile 51.8, adjacent to the Department of Fish and Game (DFG) Chinook salmon hatchery east of the town of Snelling (Figure 1). The site is the terminus for anadromous fish in the lower Merced River, and is located in the midst of a large reach of gold dredger tailings.

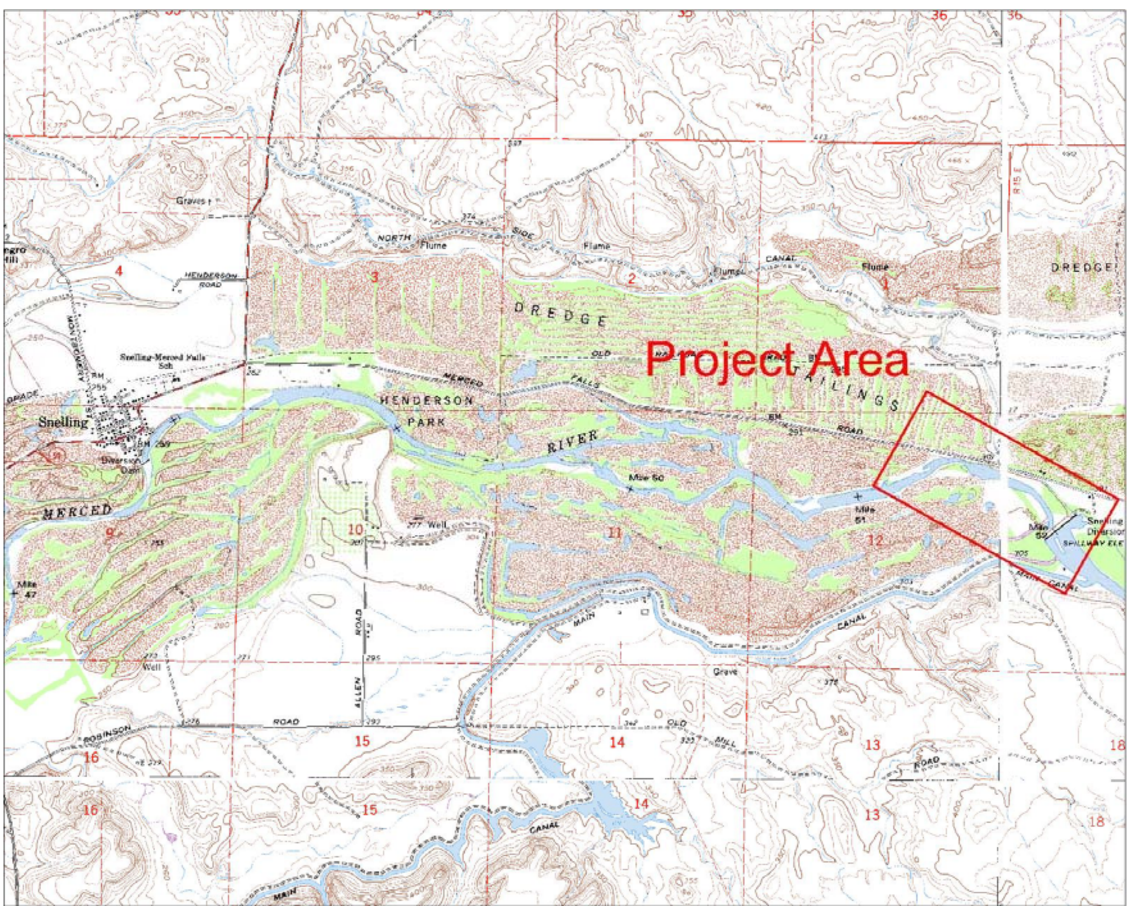

Figure 1. Site Location Map

History

In 1990, the "Merced River Gravel – Phase I" was constructed. This project was the first spawning habitat restoration project funded under the "Four Pumps" agreement. With an originally estimated project life of 15-years with maintenance, gravel has been replenished four times since the date of construction in 1990. The most recent gravel augmentation was in July of 2003.

Gravel Augmentation

Design

The augmentations of 1996, 1997, and 2000 specified location of gravel placement to be exclusively in the split-flow reach and specified elevations to follow the original 1990 design. However, the elevation of gravel placed below section 2740+35 (Figures 2, 6), where the original design called for a grade drop, was raised during construction to eliminate the drop and provide cover over the downstream boulder structures (Figure 2). The 2003 augmentation also followed this practice but included areas downstream of the split flow to extend the spawning reach. In all cases, the gravel was placed and then raked with the loader to introduce an irregular surface to encourage interfluvial flow, which is believed to be a preferred characteristic for spawning salmon.

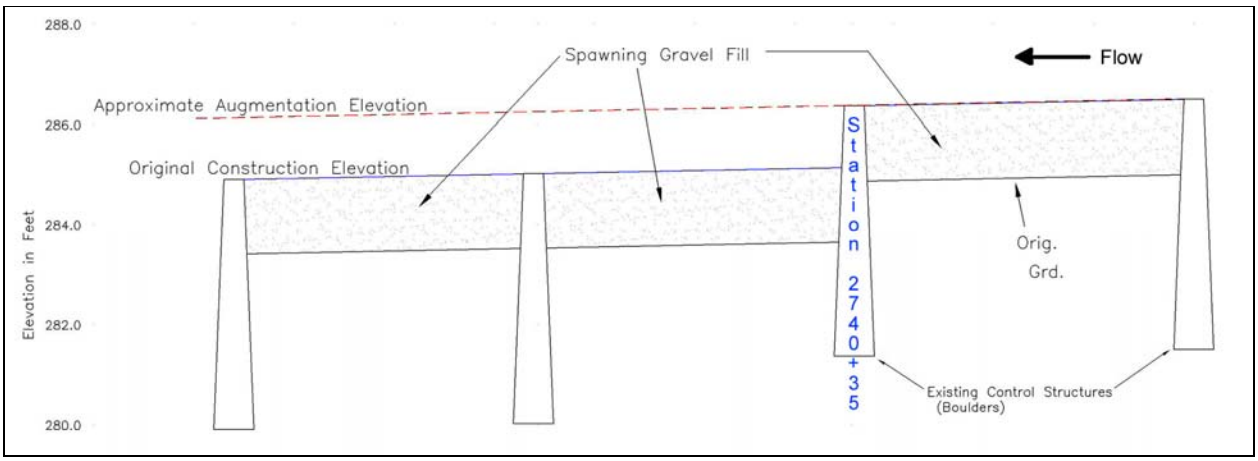

Figure 2. Original Design and Augmentation Elevations at Split Flow Reach

Quantity

DWR replaced gravel at the site in 1996 after high flows had moved some gravel out of the reach. The work was done as general maintenance supported by the original Four Pumps project funding. Approximately 1,000 tons of 1/8-inch to 5-inch gravel were added to the site (Figure 3). With the same specifications, another 1,000 tons of gravel were placed in the river the next year to replenish the gravel that was moved downstream by very high flows in 1997. Three years later in 2000, again using the same specifications, another 1,100 tons of gravel were placed in the river. Finally, in 2003, approximately 1,500 tons of gravel were added to the site. The 2000 and 2003 work was funded by Four Pumps through a cost revision for maintenance of Merced River Gravel Phase I, which was budgeted to pay for up to four maintenance infusions over six years starting in 2000 (DWR/DFG, 2000). Figure 3 illustrates the year, quantity and specifications for the gravel placed at the project site during each augmentation.

Year 1990 (Phase I construction)

Quantity 3,349.00 tons

Specifications

Size	% by weight
4 to 2 - inch	20% ± 5%
2 to ½ - inch	80% ± 5%
< ½ - inch	Maximum allowance 5% No material < 1/8 - inch

Year 1996

Quantity 1,022.96 tons

Specifications

Size	*% Passing*	*% Retained*
5-inch	100	0
4-inch	85 to 90	10 to 15
2-inch	30 to 35	65 to 70
1/2-inch	0 to 5	95 to 100
1/8-inch	0	100

Year 1997

Quantity ~1,000.00 tons

Specifications

Size	*% Passing*	*% Retained*
5-inch	100	0
4-inch	85 to 90	10 to 15
2-inch	30 to 35	65 to 70
1/2-inch	0 to 5	95 to 100
1/8-inch	0	100

Year 2000

Quantity 1,138.53 tons

Specifications

Size	*% Passing*	*% Retained*
5-inch	100	0
4-inch	85 to 90	10 to 15
2-inch	30 to 35	65 to 70
1/2-inch	0 to 5	95 to 100
1/8-inch	0	100

Year 2003

Quantity 1,493.73 tons

Specifications

Size	*% Passing*	*% Retained*
6-inch	100	0
5-inch	95 to 100	0 to 5
2-inch	60 to 75	25 to 40
1/2-inch	0 to 10	90 to 100
1/8-inch	0	100

Figure 3. Gravel Addition Summary

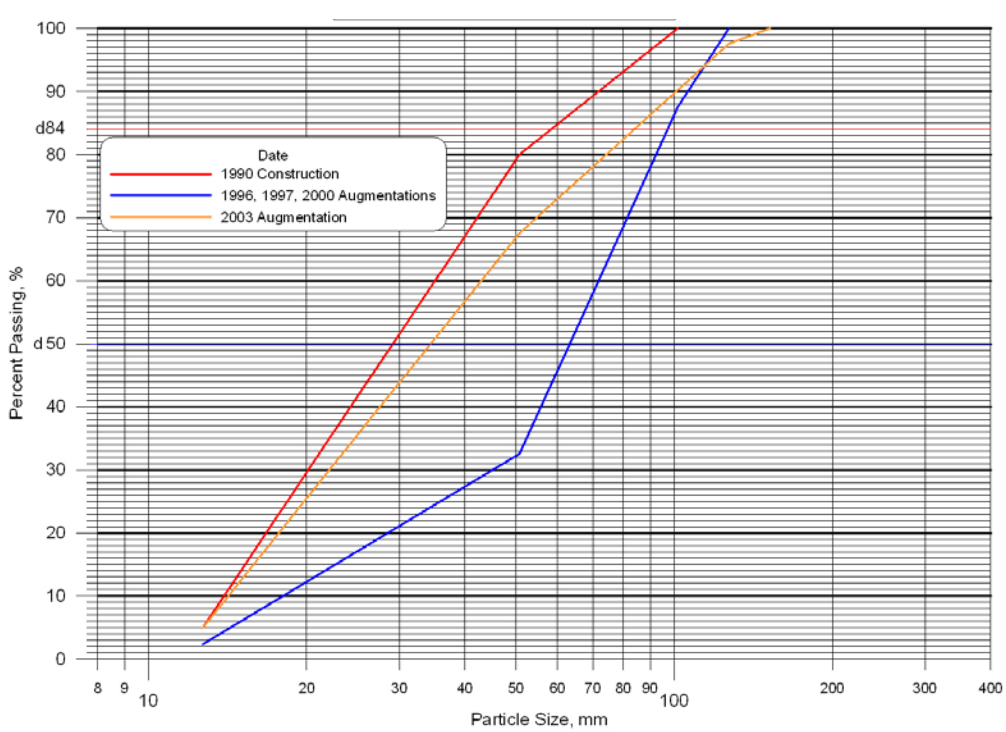

Figure 4. Imported Gravel Specifications

Size & Specification

The gravel sizes selected for the specifications in Figure 4 took into consideration spawning suitability and mobility. The size criteria was developed using a combination of typical screen sizes that gravel plants use and the typical size range for spawning material, which is ½ to 4 inches (DWR, 1994). Gravel specifications from previous projects were also used to determine the breakdown for each size.

Although gravel sizes were selected considering the above spawning factors, they should also be determined by mobility. Sizes typically are selected such that during the 1.5 to 2 year (approximately 1,400 and 2,300cfs, respectively) event the gravel is predicted to move. However, there has been some debate as to whether this frequency of movement is desirable when there is no opportunity for gravel to move in to replace it from upstream.

Purpose

The purpose of this report is to summarize and analyze the monitoring data collected since the completion of the original project, and to offer recommendations for improvement of the augmentation and monitoring plans.

GOALS AND OBJECTIVES

Project Goals

The general goal of this project is to increase the quality and quantity of spawning habitat for fall run Chinook salmon on the Merced River. Specifically, the goal is to maintain and enhance critical existing spawning habitat.

Monitoring Goals

The goal of the monitoring program is to collect data through tools such as section profile surveys and pebble counts, which should allow us to evaluate the gravel and channel conditions so that we can answer the geomorphologic questions related to gravel quality, mobility, and quantity in the project reach. The goal of the monitoring report is to present and analyze the data and make further recommendations.

HYDROLOGY

Mean daily flow records for the Department of Water Resources (DWR) Snelling stream gauge, located at River Mile 47.8 downstream of the project site, were downloaded from the California Data Exchange Center (CDEC). The records were used to generate a hydrograph from 1990 to 2003 (Figure 5). The figure also includes construction, survey and augmentation dates.

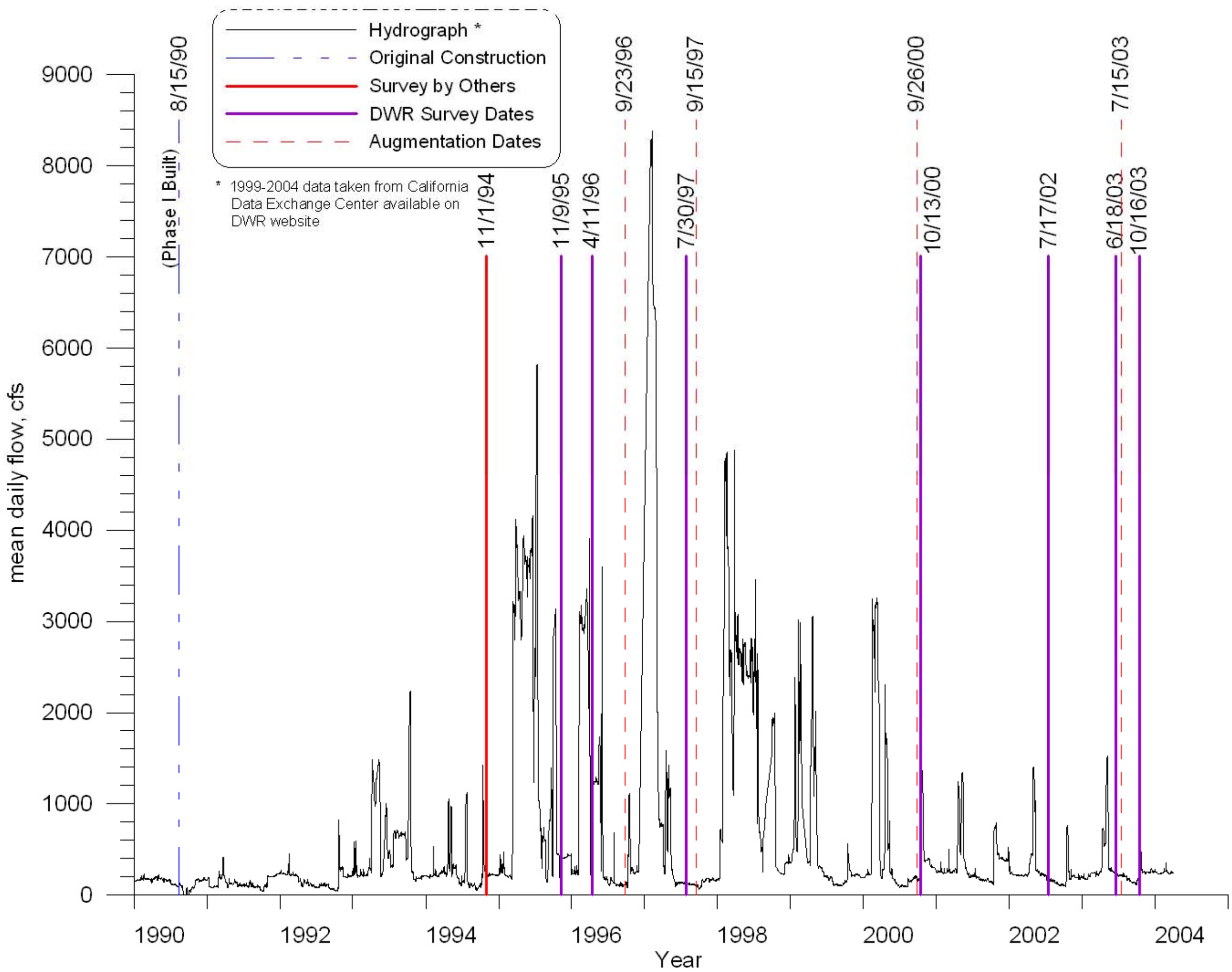

Figure 5. Hydrograph for Merced River Near Snelling with construction and monitoring history

GEOMORPHIC MONITORING ACTIVITIES

Monitoring cross-sections, which are established perpendicular to the direction of flow, are used to measure physical channel characteristics, stream discharge, and particle size distribution. Monitoring of the site consisted of taking cross-sectional surveys and conducting pebble counts (Wolman, 1954). Gravel monitoring was performed before and after construction and if possible, after a major event. The solid colored lines in Figure 5 denote the dates when cross-sectional surveys and pebble counts occurred, and Table 1 shows the locations and dates of the surveys along with significant flow events and augmentation dates. Figure 6 is a site map of the project showing the location of the original project as designed along with the monitoring section locations.

Cross-Section Surveys

Over the years between 1996 and 2003, DWR performed surveys to record channel bed elevations on several cross-sectional profiles. Up to 8 sections were monumented and surveyed, with another 6 surveyed occasionally using landmarks such as the boulder structures to locate them. The 8 cross–sections that are monumented were done so with lengths of steel rebar used as pins set at both ends of each section. The surveys were performed using a total station and data collector. This method allows monitors to map each point so that relative locations are apparent, and when survey points veer too much away from the monitoring section line they can be ignored. In some cases this occurred and partial sections were left out of comparison plots discussed in the results section.

Pebble Counts

In order to determine the bed characteristics of the project site, the Wolman pebble count was used. This procedure involves taking samples along the monitoring section, measuring the sample along its intermediate axis, and tallying them according to typical sieve sizes. The data was taken before and after gravel placement and used to generate the average size distribution curves presented in the results section.

Not only do these plots illustrate the size distribution of the gravel placed in the river, but the data is also used to determine the D_{50} (median grain diameter) and the D_{84} (the size at which 84% of the sample is finer) of the bed material. This information is useful in sediment transport calculations.

Section > Year v	2735+02	2736+74	2738+07	2738+38	2738+70	2738+90	2739+03	2739+40	2739+67	2739+92	2740+35	2740+54	2740+91	2742+57
1990			original construction											
1994								survey		survey		survey		
1995														
	5,820 cfs	5,820 cfs	5,820 cfs	5,820 cfs	5,820 cfs	5,820 cfs	5,820 cfs	5,820 cfs	5,820 cfs	5,820 cfs	5,820 cfs	5,820 cfs	5,820 cfs	5,820 cfs
							survey		survey		survey		survey	
1996														
	3,910 cfs	3,910 cfs	3,910 cfs	3,910 cfs	3,910 cfs	3,910 cfs	3,910 cfs	3,910 cfs	3,910 cfs	3,910 cfs	3,910 cfs	3,910 cfs	3,910 cfs	3,910 cfs
	survey	survey	survey			survey		survey		survey		survey		survey
							augment	augment	augment	augment	augment	augment	augment	
1997	8,520 cfs	8,520 cfs	8,520 cfs	8,520 cfs	8,520 cfs	8,520 cfs	8,520 cfs	8,520 cfs	8,520 cfs	8,520 cfs	8,520 cfs	8,520 cfs	8,520 cfs	8,520 cfs
	survey	survey	survey			survey		survey		survey		survey		survey
							augment	augment	augment	augment	augment	augment	augment	
1998														
	4,880 cfs	4,880 cfs	4,880 cfs	4,880 cfs	4,880 cfs	4,880 cfs	4,880 cfs	4,880 cfs	4,880 cfs	4,880 cfs	4,880 cfs	4,880 cfs	4,880 cfs	4,880 cfs
1999														
2000														
							augment	augment	augment	augment	augment	augment	augment	
							survey	survey			survey	survey	survey	
2001														
	1,345 cfs	1,345 cfs	1,345 cfs	1,345 cfs	1,345 cfs	1,345 cfs	1,345 cfs	1,345 cfs	1,345 cfs	1,345 cfs	1,345 cfs	1,345 cfs	1,345 cfs	1,345 cfs
2002														
	1,402 cfs	1,402 cfs	1,402 cfs	1,402 cfs	1,402 cfs	1,402 cfs	1,402 cfs	1,402 cfs	1,402 cfs	1,402 cfs	1,402 cfs	1,402 cfs	1,402 cfs	1,402 cfs
		survey		survey	survey		survey	survey	survey	survey	survey	survey	survey	
2003														
	1,530 cfs	1,530 cfs	1,530 cfs	1,530 cfs	1,530 cfs	1,530 cfs	1,530 cfs	1,530 cfs	1,530 cfs	1,530 cfs	1,530 cfs	1,530 cfs	1,530 cfs	1,530 cfs
				survey			survey		survey	survey	survey	survey	survey	
				augment	augment	augment	augment	augment	augment	augment	augment	augment	augment	
			survey	survey	survey		survey	survey	survey	survey	survey	survey	survey	

Table 1. Hatchery Site Monitoring History

Figure 6. Original Project Plan and Monitoring Section Locations

DATA RESULTS AND ANALYSIS

Cross-Section Surveys

Survey data varies for each of the monitoring sections. Several have only a few data sets, while a few have been more consistently surveyed. Appendix A contains Figures A-1 to A-14, which show the plots for each of the cross–sections referenced from the left bank looking downstream. Table 1 above shows the month in which each of the sections were surveyed.

Beginning with the farthest downstream section, 2735+02 (Figure A-1), we see that it was surveyed in 1996 and 1997. This section is nearly 300 feet downstream of any construction or augmentation activity, but it can be used to indicate whether gravel is being moved downstream from the augmentation site. Between the two surveys at this section, there was a high flow of 8,520cfs, which is the highest flow recorded since original construction. However, the plotted survey data show little change.

The next section upstream, 2736+74 (Figure A-2), is also downstream of the construction and augmentation areas. It was surveyed in 1996, 1997, and 2002. Like the previous section, it is used to show whether gravel is moving downstream from the augmentation site. It seems to show that some volume of material was lost at the section during the 1997 high flows, but subsequent flows of up to 4,880cfs (1998) between 1997 and 2002 changed the section very little.

Section 2738+07 (Figure A-3), the next section upstream, is the lower-most monitoring section that is within the original 1990 project construction area. The plotted section shows the design elevation as well as survey data from 1996, 1997, and 2003. The plots indicate that the channel bottom had degraded by up to two feet within the left half of the channel prior to 1996, presumably as a result of flows that reached 5,820cfs (1995). The 1996 augmentation was undertaken after the survey, but presumably did not extend this far downstream. The flows experienced between the 1996 and 1997 surveys apparently moved even more gravel out of the section, as the channel shows more degradation in the 1997 profile. Moving to the 2003 survey, it is difficult to know how flows affected the section in the meantime because the last survey was done after the 2003 augmentation. Although the 2003 augmentation plan called for gravel placement to stop upstream of this section, excess imported gravel apparently allowed for augmentation through this section. The 2003 survey shows the gravel at almost one foot above 1990 design grade.

Section 2738+38 (Figure A-4) is located directly on one of the boulder control structures built in 1990 (the structures were originally intended to help keep gravel in place). It marks the lowest point for planned augmentation in 2003, but it is about 60 feet downstream of the planned area for earlier augmentations of 1996, 1997, and 2000. Survey data for 2002, June 2003, and October 2003 are shown on the profile for this section. It appears that grade has been held at this section, which would be expected due to the large size of the boulders placed during the original construction and lack of high flows. The post-augmentation survey in 2003 shows that gravel was placed up to 1 foot above the original design elevation for this section as well.

Section 2738+70 (Figure A-5) is in the middle of the lowest cell augmented in 2003. It is below the planned augmentation areas for 1996, 1997, and 2000, but because the access ramp enters the river at this point the section was likely affected during those work periods. This section was not surveyed before 2002, but data is shown for that year and post-augmentation 2003, as well as the design elevation. The 2002 survey shows a profile that is not much removed from the original 1990 design elevation. It is difficult to conclude whether this lack of change is due to either low mobility or to gravel being moved into this section from upstream because of the possibility of gravel placement during the earlier augmentations and the fact that equipment traveled through this section during those augmentations. As with the previous sections, the 2003 survey shows that gravel was placed above 1990 design grade in 2003.

Section 2738+90 (Figure A-6) is located immediately below the island that splits the channel upstream of this location. It is also immediately below the next boulder structure. Survey data were taken in 1996 and 1997 just before those augmentations were put in place. They show that between the original 1990 construction and the 1996 survey there was not much change in bed elevation at this point even though flows of up to 5,820cfs occurred. However, the following year’s survey showed a drop in bed elevation after the 8,520cfs flow that year.

Section 2739+03 (Figure A-7) is only an average of 13 feet upstream of the previous section. It is located on the boulder structure that forms the downstream border of augmentations undertaken in 1996, 1997, and 2000. The section was surveyed in 1995, 2000, 2002, and before and after the 2003 augmentation. The 1995 profile shows that the boulder structure was still in place near design grade before any augmentations were conducted. The later profiles show that new gravel was consistently placed 0.5 to 1 foot above original design grade.

Section 2739+40 (Figure A-8) is located in the middle of the downstream split-flow cell between two boulder structures. It is one of the most consistently monitored sections, with surveys in 1996, 1997, 2000, 2002, and 2003. Survey data was published in Kondolf et al. (1996) for this section from 1994 as well, and it is shown with our survey data on the profile figure. Some of the survey data from 2000, 2002, and 2003 was not taken close enough to the monitoring section and was excluded, which is why the data does not extend all the way across for those surveys. However, enough data exists to show that high flows before the 1996 and 1997 augmentations were significant enough to move gravel out of this section and leave it degraded up to more than 1 foot below design grade, particularly in the main channel. Later surveys show that the 2000 and 2003 augmentations left the section up to 1 foot above 1990 design grade as is the case for the previous sections. Some movement of gravel is indicated in the right channel between the 2000 and 2003 survey even though flows never exceeded 1,530cfs, but this is likely explained by the DFG practice of moving the gravel around during augmentation so that an irregular surface is left to encourage interfluvial flow.

Section 2739+67 (Figure A-9) is located on another of the boulder structures. Surveys of 1995 and 2003 (pre-augmentation) are shown for the main channel and 1995, 2002, and pre- and post-augmentation 2003 are shown for the side channel. The side channel surveys do not show much movement or change, but the main channel surveys show that in 1995 the channel profile was significantly lower than design. This may indicate movement of the boulder structure, although the location of the survey is slightly upstream of the design location of the structure so may have missed the bulk of it. The pre-augmentation 2003 survey shows a profile almost 1 foot above design, indicating no movement since the 2000 augmentation. Flows during that period did not exceed 1,530cfs.

Section 2739+92 (Figure A-10) is located in the middle of the center cell of the split-flow reach. It is another section that has been extensively monitored, with surveys in 1996, 1997, 2002, and pre- and post-augmentation 2003, as well as the 1994 Kondolf survey. The 1994 survey showed some aggradation in the main channel, although flows did not exceed 2,240cfs prior to that date. Between that date and the date of the 1996 survey, however, significant degradation occurred in both the main and side channels, with flows reaching up to 5,820cfs in that period. The gravel was replaced during the 1996 augmentation, but the flows of 1997 moved it out again, with the main channel profile returned to an almost identical state. The surveys of 2002 and 2003, taken after the 2000 augmentation, show the bed stable at about 1 foot above 1990 design grade in the main channel. In the side channel, the bed elevation actually dropped after the 2003 augmentation, presumably due to the raking of the bed previously mentioned.

Section 2740+35 (Figure A-11) is located immediately upstream of the next boulder structure. That structure is the one originally designed to step the bed level down approximately 1 foot moving downstream (see Figure 2). Survey data is available for 1995, 2000, 2002, and pre- and post-augmentation 2003. The 1995 survey shows significant degradation at the section due to flows up to 5,820cfs. The other surveys, taken after augmentation and during a period of relatively low flows, show little movement in the main channel bed, with elevations close to the 1990 design. The side channel survey shows that in 2002, the bed was significantly higher than in 2000. Flows were not high enough to move the gravel, so unless there was some channel work done in this area during that period that we are unaware of, the only other explanation is survey error.

Section 2740+54 (Figure A-12) is located mid-cell in the upper portion of the split-channel reach. It also has been extensively monitored, with surveys in 1996, 1997, 2000, 2002, two in 2003, and the 1994 Kondolf survey. The pre-augmentation 1994 and 1996 surveys show significant degradation of the channel due to flows of up to 2,240 and 5,820cfs respectively. The survey of 1997, after the 1996 augmentation and subsequent high flow of 8,520cfs, shows even more degradation in the main channel but none in the side channel. Later surveys all show bed elevations close to the 1990 design elevation.

Section 2740+91 (Figure A-13) is the uppermost monitoring section located within the augmentation reach, and extends across the upper boulder structure. Surveys show that bed elevations do not vary greatly, although they indicate that some of the boulders may have moved at some point because the 1995, 2002, and 2003 pre-augmentation surveys all show elevations somewhat below 1990 design.

The farthest upstream monitoring section is 2742+57 (Figure A-14). This section is used to monitor effects upstream of the augmentation site. Survey data from 1996 and 1997 show that no significant changes occurred during the high flows of 1997.

Pebble Counts

Distributions

Pebble count data was recorded in July 1997, September 1997, October 2000, July 2002, June 2003, and October 2003. All of the pebble counts were performed by DWR with the exception of the 2000 counts, which were performed by staff at Stillwater Sciences. The results are presented in graphs for each cross-section in Appendix B. Where available, split flow sections are presented with data for each channel. In addition, post-augmentation pebble counts are presented as combined averages for the augmented sections because of the homogeneous character of the imported gravel. In some cases, the average may be the only data available for a particular date for a section, but when available, the individual pebble count is presented as well.

Sections 2735+02 and 2736+74 (Figures B-1 and B-2), located downstream of the original project site, were sampled in 1997 only. The D_{50} and D_{84} sizes for the two are remarkably similar at about 86mm and 170mm, respectively.

The next section with pebble count data is 2738+90 (Figure B-3). This section is located directly below the split flow portion of the site. It has been extensively monitored with pebble counts in July 1997, July 2002, June 2003, and October 2003. Also shown on the figure are average post-augmentation pebble counts for September 1997, October 2000, and October 2003, which show a distribution that includes all pebble counts for those dates within the augmentation reach. The figure shows a much flatter curve for July 1997, with D_{50} (87mm) and D_{84} (170mm) sizes significantly larger than those for any of the other dates. Taken with the cross-sectional profile that shows a degraded bed at this section, it appears that much of the 1996 augmentation material was removed in the 1997 high flows, and larger native material dominated what was left. Most of the other curves do not diverge from the group much, although the right-channel measurements appear to be smaller than the right-channel measurements overall.

Section 2739+40 (Figures B-4 and B-5) has also been consistently monitored. It is the lowest of three monitoring sections located in the middle of the most frequently augmented cells of the site. Pebble counts were performed for this section in July 1997, September 1997, July 2002, and October 2003. The figures show results for the left and right channel separately. As with the previous section, the July 1997 distribution for the left channel stands out as having a much larger composition than the others. However, the right channel distribution for that date looks similar to those taken on the other dates.

Section 2739+92 (Figures B-6 and B-7) is located in the middle of the next cell. The trends for the distributions are similar to those of 2739+40.

The left and right channel pebble count distributions for section 2740+35 are shown in Figures B-8 and B-9. The only individual pebble count taken on this section was in June 2003, but it is shown in the figures with the averages for September 1997, October 2000, and October 2003.

Section 2740+54 (Figures B-10 and B-11) is located in the middle of the upper augmentation cells. The trends for these pebble count distributions are similar to those of 2739+40 and 2739+92, with most distributions closely aligned with the exception of the July 1997 one in the left channel.

The uppermost section with pebble count data available was 2742+57 (Figure B-12). This section is upstream of the Phase I construction site and current augmentation site, but has been monitored to record possible upstream effects of the project.

Particle Size vs. Time

Appendix C contains figures that show the D_{50} and D_{84} plotted against time for several of the pebble count distributions discussed above. Also shown on these plots are the flows experienced at the site and the dates of construction and gravel augmentation. The figures show the influences on the gravel and when they occurred.

Figures C-1 through C-4 show the results for several of the sections within the augmentation reach. They show some trends in gravel sizes that are fairly consistent, including much higher D_{50} and D_{84} values prior to the 1997 augmentation, and a tendency for the right channel sizes to be somewhat smaller than those in the left channel. Gravel composition also shows mild but consistent coarsening for each of the sections for the 2002 pebble count, which was taken at a time when flows had not reached significant levels but gravel had been in place for two years. The average increase in D_{50} and D_{84} was 9.7% and 12.5%, respectively.

Figure C-5 shows results at section 2742+57, which is upstream of the augmentation reach. That chart shows an increase in gravel size over time between 1997 and 2002. Sizes for 1997 were fairly low, probably as a result of earlier augmentation work upstream of the spawning channel by DFG at “Maury’s Riffle” site. The smaller particles appear to be gradually moving downstream from there, causing the overall composition to coarsen as the smaller particles are depleted.

Sediment Transport Calculations

Critical Shear Calculations

In order to estimate the force required to mobilize given particle sizes (i.e. D_{50} or D_{84}), the Shields equation was used,

$$\tau_{ci} = \tau^*_{ci} (\rho_s - \rho_f)\, g\, D_i,$$

where τ_{ci} is the critical shear stress (N/m^2) required to mobilize particle size D_i, τ^*_{ci} is a critical dimensionless shear stress, ρ_s is the density of the sediment (2,650 kg/m^3), and D_i is the particle diameter. τ^*_{ci} can be calculated using Andrews’ equation,

$$\tau^*_{ci} = 0.0384\, (D_i/D_{50})^{-0.887} \quad \text{(Andrews, 1994)}.$$

Andrews states that marginal bed load transport describes the condition when relatively few bed particles are moving at any time. According to Andrews, this depends on the position of particle in the channel bed and the τ^*_{ci} necessary to initiate gravel movement. If the particle is naturally deposited, smaller particles will tend to be “shadowed” by the larger particles, thus requiring a higher τ^*_{ci} for particle movement. τ^*_{ci} can range from 0.02 to 0.06, where a substantial amount of movement occurs when τ^*_{ci} exceeds 0.06. However, Andrews claims that bed particles resting in the shallowest bed pockets will move when the dimensionless shear stress exceeds a value of about 0.020. Therefore, if τ^*_{ci} increases, then the number of bed particles moving increases. The critical dimensionless shears and critical shears were calculated using pebble count data. D_{50} and D_{84} diameters, as well as the corresponding critical shears, are shown in Table 2 for four monitoring sections.

		Pebble count data							
		July-97		October-00		July-02		October-03	
section	size	particle size (mm)	critical shear (N/m2)	particle size (mm)	critical shear (N/m2)	particle size (mm)	critical shear (N/m2)	particle size (mm)	critical shear (N/m2)
2738+90	D_{50}	87	54.1	72	44.8	78	48.5	70	43.5
left	D_{84}	170	58.3	110	47.0	120	50.9	112	45.9
2738+90	D_{50}	87	54.1	72	44.8	78	48.5	67	41.6
right	D_{84}	170	58.3	110	47.0	120	50.9	96	43.4
2739+40	D_{50}	160	99.5	72	44.8	78	48.5	71	44.1
left	D_{84}	240	104.1	110	47.0	130	51.4	101	45.9
2739+40	D_{50}	73	45.4	72	44.8	78	48.5	77	47.9
right	D_{84}	120	48.0	110	47.0	130	51.4	110	49.8
2739+92	D_{50}	145	90.1	72	44.8	82	51.0	77	47.9
left	D_{84}	270	96.7	110	47.0	120	53.2	110	49.8
2739+92	D_{50}	58	36.0	72	44.8	82	51.0	68	42.3
right	D_{84}	97	38.2	110	47.0	120	53.2	96	44.0
2740+54	D_{50}	85	52.8	72	44.8	78	48.5	72	44.8
left	D_{84}	300	97.1	110	47.0	125	51.1	110	47.0
2740+54	D_{50}	73	45.4	72	44.8	78	48.5	45	28.0
right	D_{84}	110	47.5	110	47.0	125	51.1	90	30.3

Table 2. Critical Shear by Section for D_{50} and D_{84}

Mobility

A comprehensive mobility analysis, including an HEC-RAS model, is outside the scope of this report; however, based on the information from the pebble count and survey data, we can approximate the flows at which the imported gravel is mobilized. Table 3 contains approximate changes in both cross-sectional area of gravel and in D_{84} sizes for the left channel resulting during periods with maximum flows as listed. Monitoring sections were chosen that had more complete data sets and were located in the augmentation reach. Results show that each section experienced changes in gravel area of less than 10 square feet during the lower flows of 1,530cfs and 1,402cfs. That range of change is relatively insignificant and should not be considered conclusive evidence of mobility. At flows up to 5,820cfs, sections 2739+40 and 2739+92 both showed significant degradation of the channel bed, but the lowest section, 2738+90, showed slight aggradation. Section 2740+54 showed minimal change in area at this flow, probably because the channel had already been largely scoured before the first survey. At flows up to 8,520cfs, all four sections showed significant scour of more than 100 square ft.

The changes in gravel size shown in the table are only available for the lower flows. Changes in D_{84} during flows of up to 1,402cfs were all positive, with increases ranging from 9% to 18%, indicating a slight coarsening of the gravel size distribution. The lone available change for flows up to 1,530cfs registered a drop in size of 17%.

Section		8,520cfs	5,820cfs	1,530cfs	1,402cfs
2738+90	area (ft^2)	-149*	+22	n	n
	D_{84} (%)	n	n	0	+9
2739+40	area (ft^2)	-115*	-44	n	i
	D_{84} (%)	n	n	n	+18
2739+92	area (ft^2)	-100*	-81	+8	n
	D_{84} (%)	n	n	-17	+9
2740+54	area (ft^2)	-101*	-9	i	+9
	D_{84} (%)	n	n	n	+14

Area changes are in total gravel gained (+) or lost (-)
n - no data available
i - incomplete data
* - Based on assumed 1996 as-built elevation

Table 3. Monitored Changes in Left Channel Cross-section Area and Particle Size at Various Flows

DWR performed sediment transport calculations in 1996 using the information from that year's cross-section survey. Estimates of the forces applied to the channel bed by the flow were calculated using the following formula,

$$\tau_b = \rho_f \, g \, R \, S;$$

τ_b is bed shear stress (N/m^2); ρ_f is the density of water; g is gravity; R is the hydraulic radius; and S is the energy slope. The hydraulic radius (R), is calculated by A/wp, where A is the cross-sectional area and wp is the wetted perimeter. This information was taken from the cross-sectional surveys. The slope can also be estimated from the surveyed water surface elevation.

The flows used in the bed shear calculations were 278cfs and 3,100cfs. The flows selected were from surveys done at the time. The higher flow was staked and later surveyed for high water elevations. Table 4 summarizes the bed shear of both flows for cross-sections 2739+40, 2739+92, and 2740+54.

	τ_b (N/m^2) @ 278 cfs		τ_b (N/m^2) @ 3,100 cfs	
xs	left channel	right channel	left channel	right channel
2739+40	13.5	12.2	54.1	43.6
2739+92	13.0	14.3	44.0	51.4
2740+54	12.5	12.5	44.7	42.9

Table 4. Bed Shear Stress, N/m^2

Applying these values to the critical shear calculations presented in Table 2 results in estimates for mobility for these three sections. At section 2739+40, neither the left nor right channel critical shears are exceeded by the 3,100cfs flow for any of the pebble counts. At section 2739+92, the left channel critical shear is not exceeded by the 3,100cfs shear, but the right channel critical shear is exceeded for all pebble counts except in 2002. At section 2740+54, none of the pebble count critical shears are exceeded by the 3,100cfs shear except for the right channel on October, 2003. These results would imply that most of the reach begins to be mobile at flows slightly exceeding 3,100cfs.

Spawning

Since peak flows have been below 2,000cfs over the last few years, sediment movement has been limited. However, spawning activity as a share of total Merced River spawning has increased since the augmentation in 2000, with a significant increase after the 2003 augmentation (see Figure 7). It is difficult to correlate these totals to suitability of the spawning habitat in the reach, however, because the site is at the terminus for Merced River anadromous spawners.

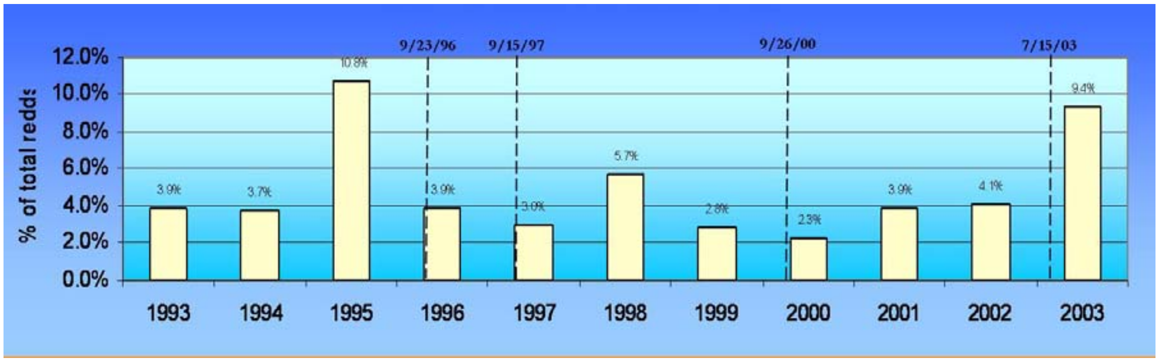

Figure 7. Merced Hatchery Site Spawning

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

DWR and DFG have taken strides in providing the necessary efforts to fulfill the goals and objectives of increasing the quality and quantity of spawning habitat on the Merced River. Though it is possible to further research the larger geomorphic context, staff, resources, and funding are a limiting factor. Meanwhile, spawning habitat is maintained and is being used until flows are great enough to move gravel out of the reach.

Based on the collected monitoring data and the sediment transport calculations, the import material is expected to move significantly during flows of between 3,100cfs and 5,800cfs. A balance between desired mobility for habitat purposes (2 year flow, or about 2,300cfs) and frequency of needed augmentations must be considered before any decision to change the composition of future gravel additions is made. Since the original project was built in 1990, 3,100cfs has only been significantly exceeded in four water years, while 2,000cfs was exceeded during three others.

Recommendations

The following are recommendations intended to improve both future monitoring and future gravel augmentation in the reach:

- **Maintain and expand the existing monitoring program**. Funding constraints have required that a minimal monitoring program be implemented for this project. We recommend an expansion of the program to include both sediment transport sampling (such as Helley-Smith sampling at various flows) and tracer gravel studies. These studies should be applied to sections 2739+40, 2739+92, and 2740+54 at a minimum. In addition, all monitoring sections should be surveyed each time rather than only surveying selected sections.
- **Increase monitoring frequency of cross-section surveys and pebble counts**. These activities should be performed before and after each augmentation and after any season during which flows have reached 2,000cfs or more.
- **Expand sediment transport study to include HEC-RAS modeling.** It is currently not possible to accurately estimate transport volumes or sizes at various flows within the reach. A HEC-RAS model would enable engineers to determine shears experienced at the monitoring sections. This would result in the ability to develop a sediment budget for the reach and to better refine import gravel sizes for mobility.

REFERENCES

1. Andrews, E.D. 1994. *Marginal Bed Load Transport in a Gravel Bed Stream*. Sagehen Creek, California. Am Geophys Union 94WR00553.

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3. California Department of Water Resources (DWR) and California Department of Fish and Game (DFG). 2000. *Proposed Project Cost Revision for Maintenance of Merced River Gravel – Phase I.*

4. Kondolf G.M., J.C. Vick, and T.M. Ramirez. 1996. *Salmon Spawning Habitat Rehabilitation on the Merced River, California: An Evaluation of Project Planning and Performance.* American Fisheries Society 125:899-912.

5. Wolman, MG. 1954. *A Method of Sampling Coarse River-bed Material.* Trans Am Geophys Union 35(6):951-6.

APPENDIX A
Cross-Sections

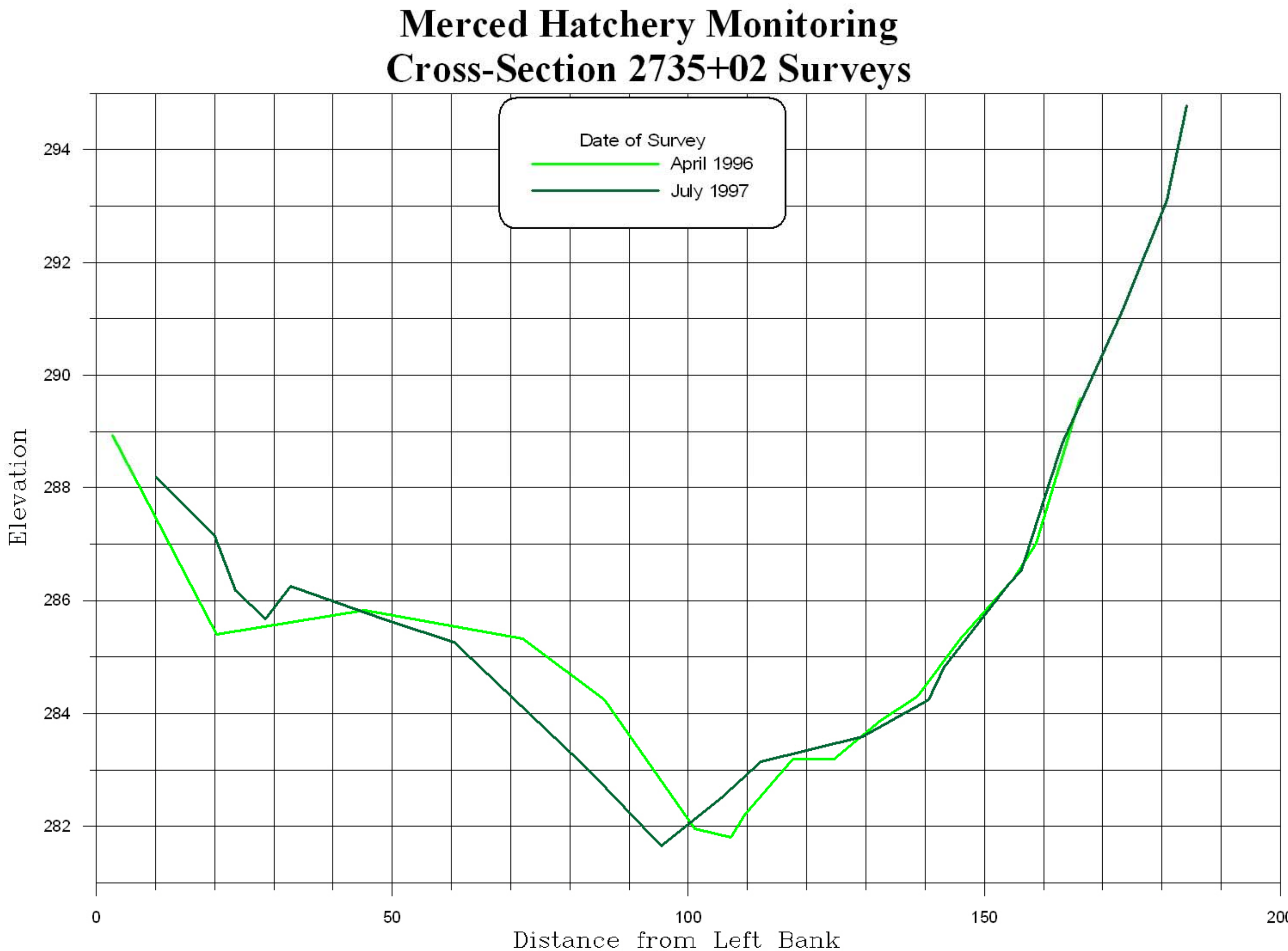

Merced Hatchery Monitoring
Cross-Section 2735+02 Surveys
Date of Survey
April 1996
July 1997
294
292
290
288
286
284
282
Elevation
0
50
100
150
200
Distance from Left Bank

Figure A-1

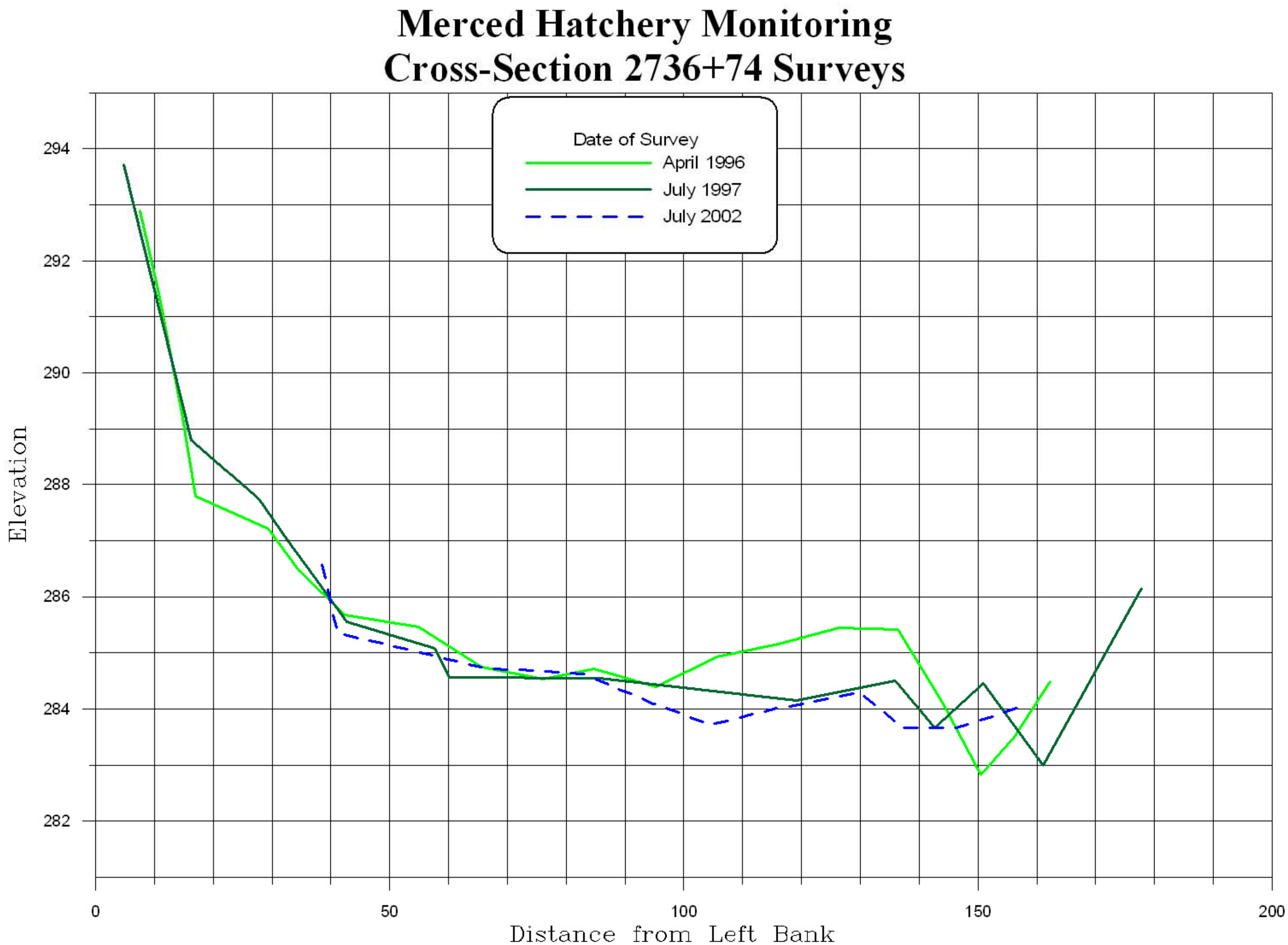

Merced Hatchery Monitoring
Cross-Section 2736+74 Surveys
Date of Survey
April 1996
July 1997
July 2002
294
292
290
288
286
284
282
Elevation
0
50
100
150
200
Distance from Left Bank

Figure A-2

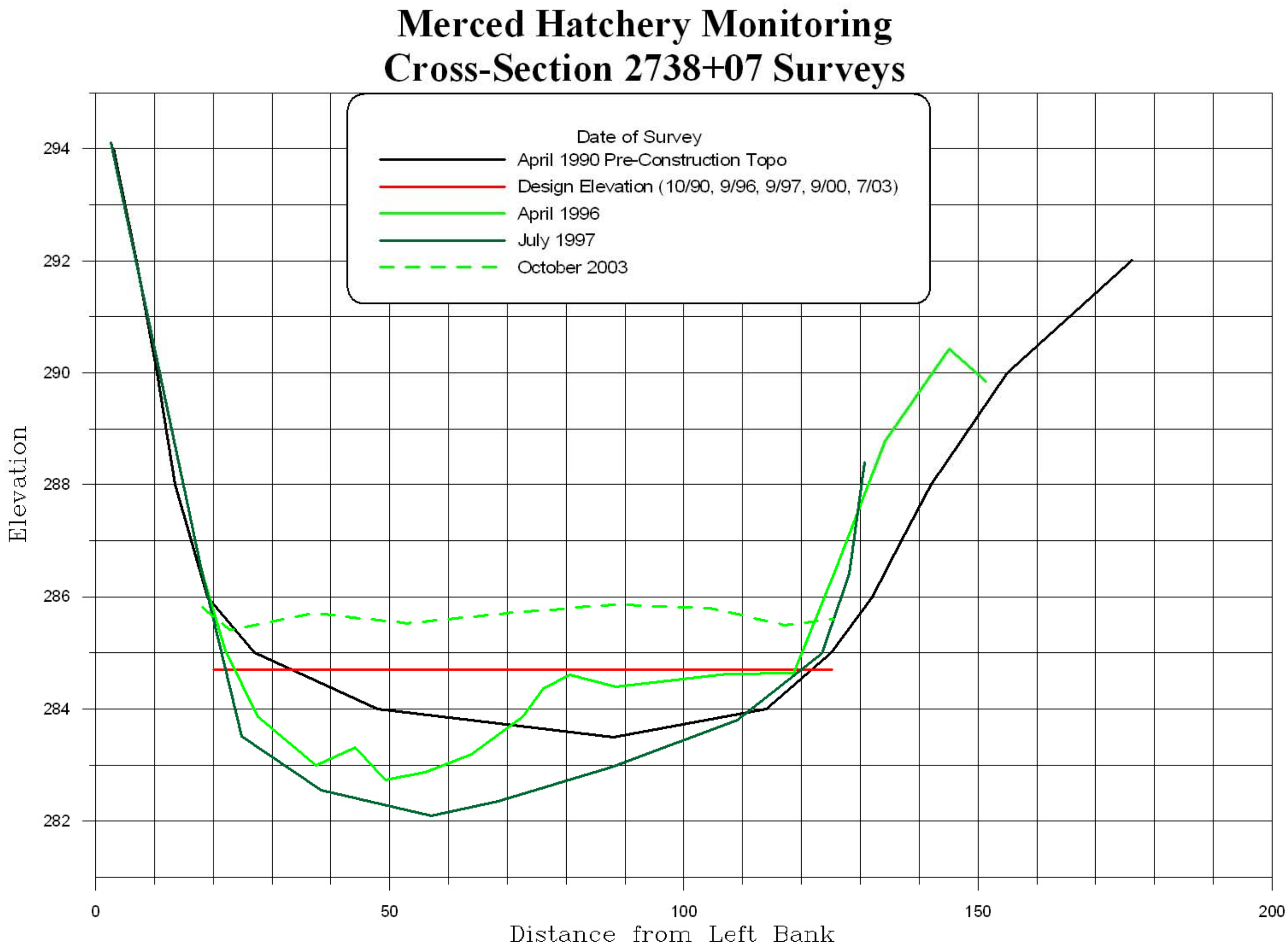
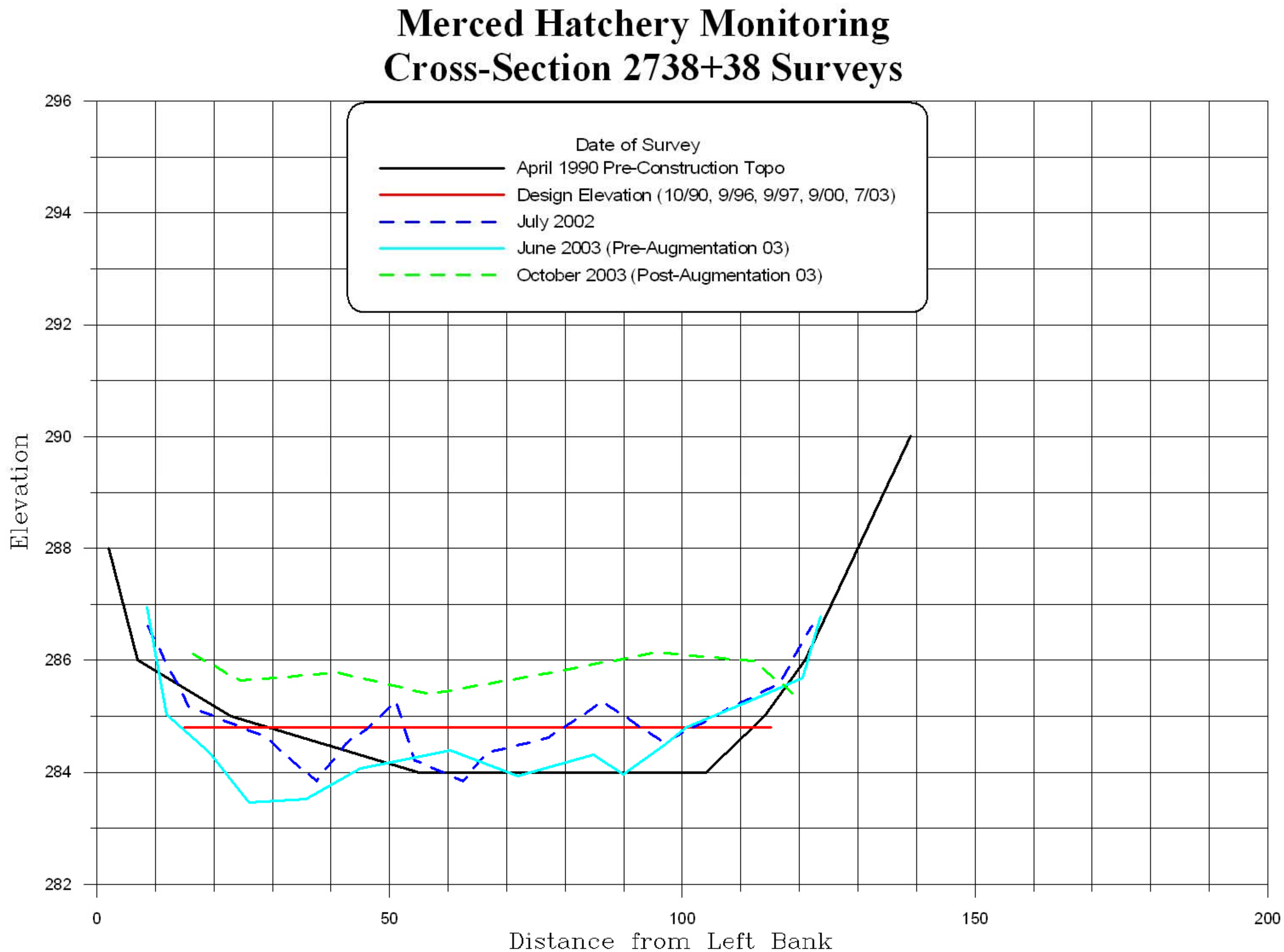

Merced Hatchery Monitoring
Cross-Section 2738+07 Surveys
Date of Survey
April 1990 Pre-Construction Topo
Design Elevation (10/90, 9/96, 9/97, 9/00, 7/03)
April 1996
July 1997
October 2003
Elevation
294
292
290
288
286
284
282
0
50
100
150
200
Distance from Left Bank

Figure A-3



Merced Hatchery Monitoring
Cross-Section 2738+38 Surveys
Date of Survey
April 1990 Pre-Construction Topo
Design Elevation (10/90, 9/96, 9/97, 9/00, 7/03)
July 2002
June 2003 (Pre-Augmentation 03)
October 2003 (Post-Augmentation 03)
Elevation
296
294
292
290
288
286
284
282
0
50
100
150
200
Distance from Left Bank

Figure A-4

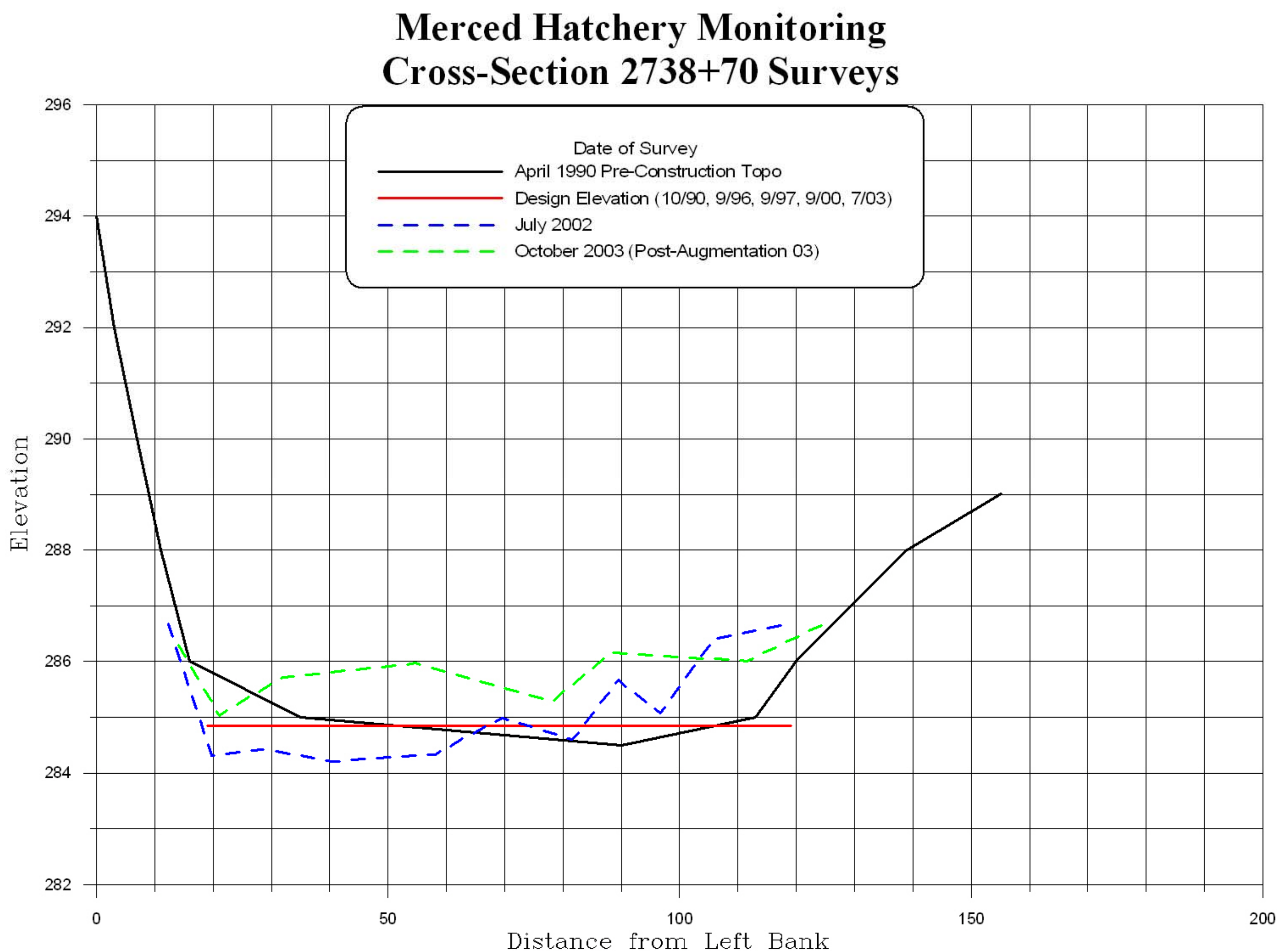

Merced Hatchery Monitoring
Cross-Section 2738+70 Surveys
Date of Survey
April 1990 Pre-Construction Topo
Design Elevation (10/90, 9/96, 9/97, 9/00, 7/03)
July 2002
October 2003 (Post-Augmentation 03)
Elevation
296
294
292
290
288
286
284
282
0
50
100
150
200
Distance from Left Bank

Figure A-5

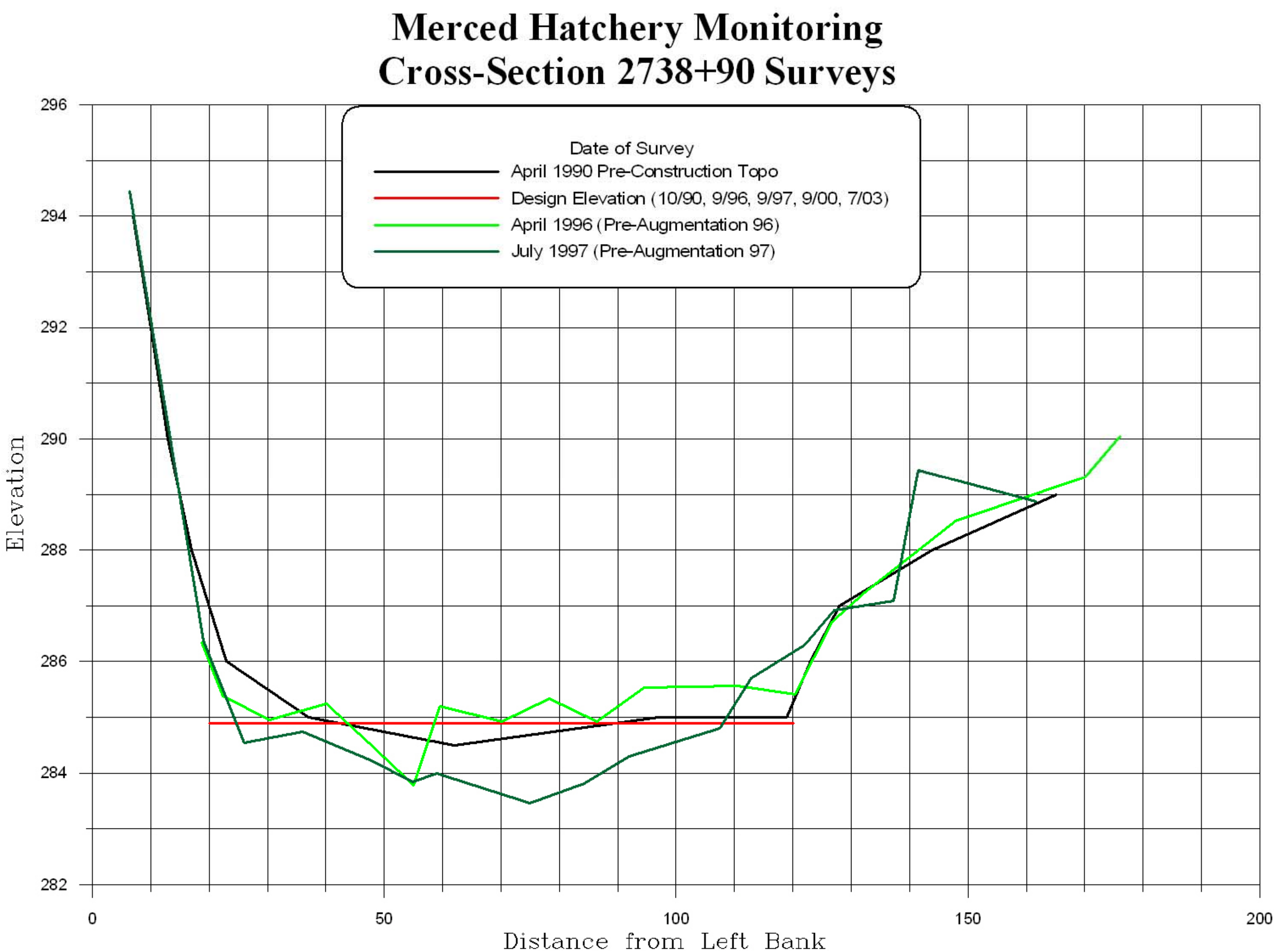
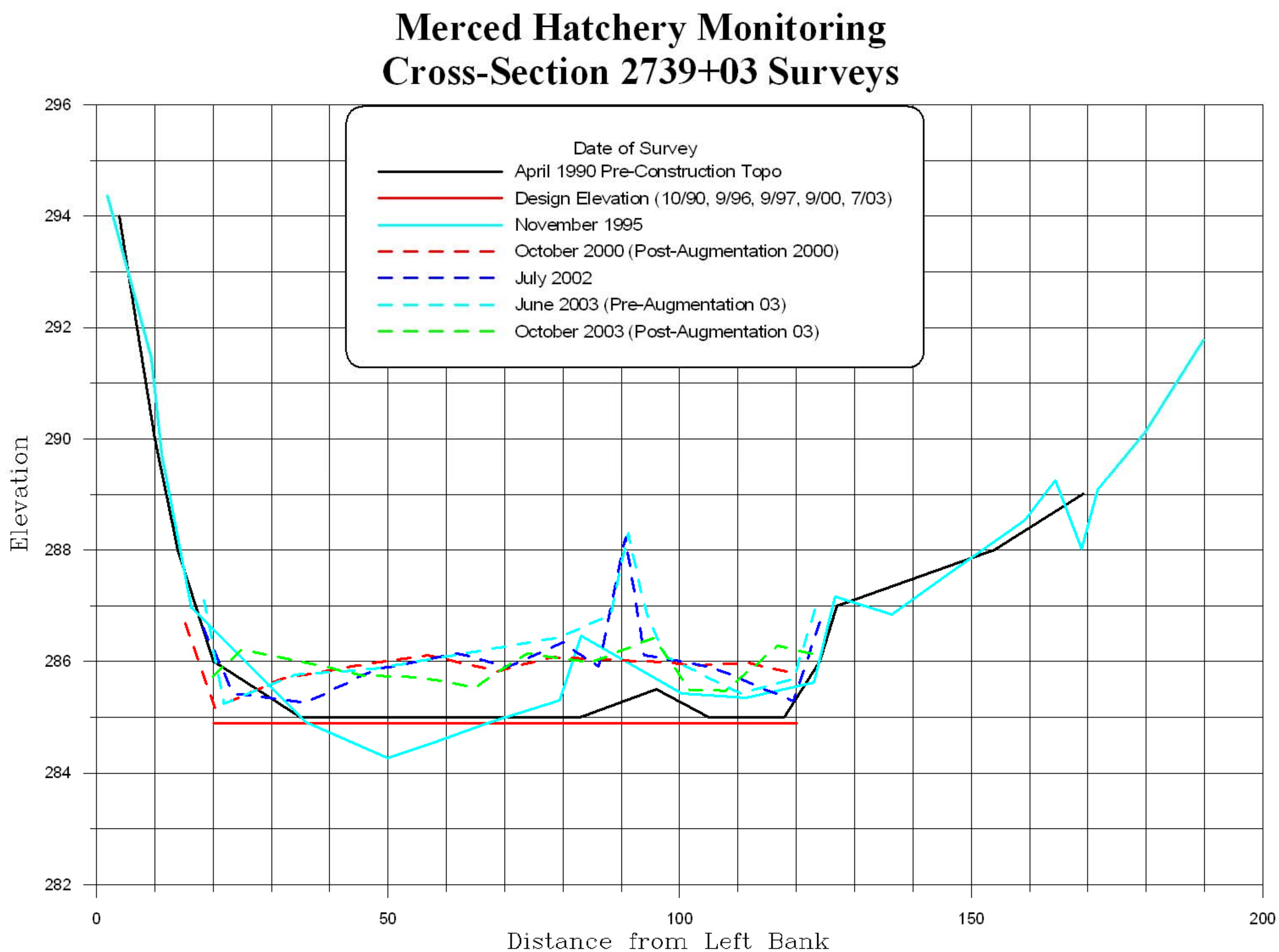
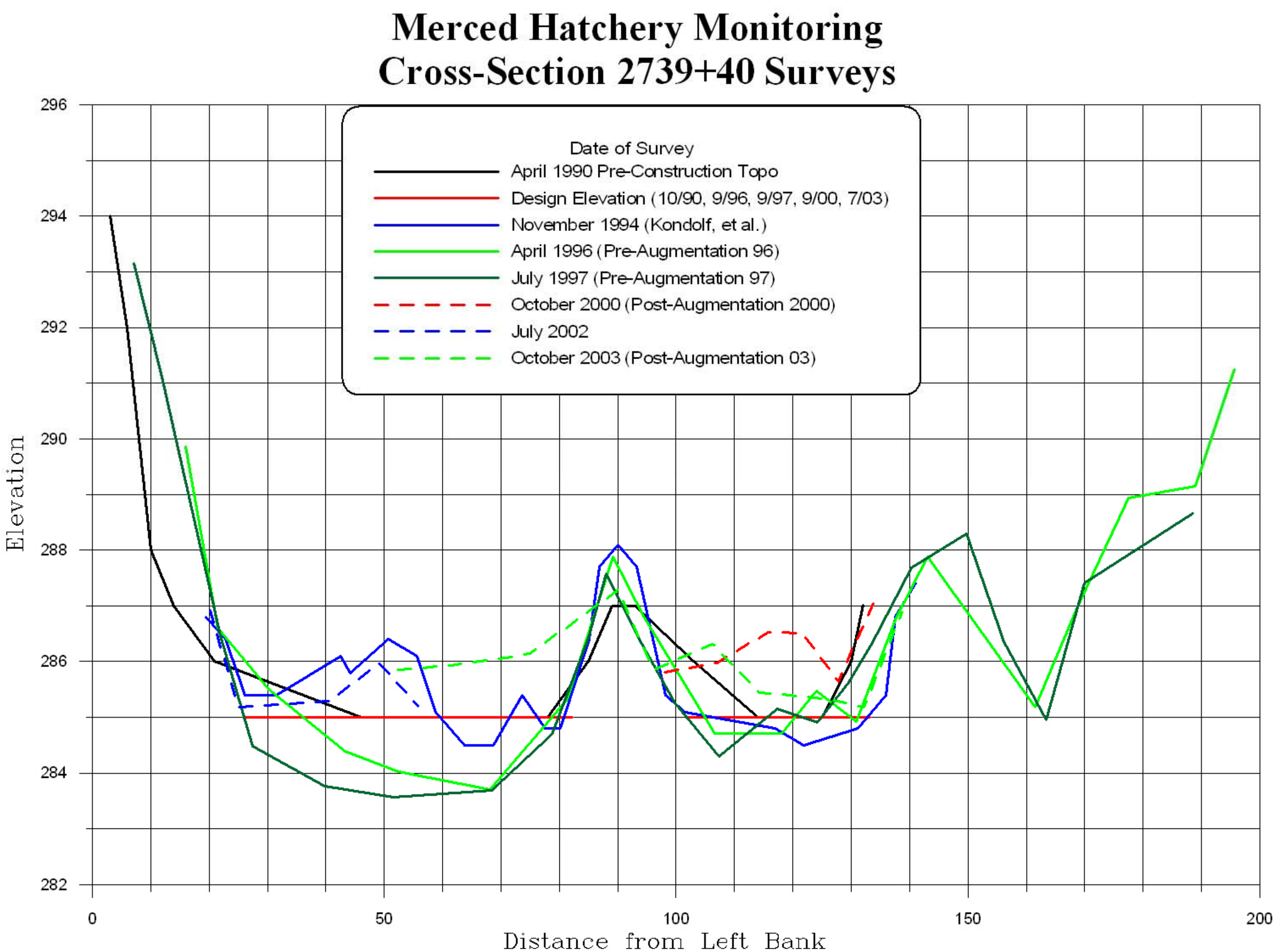

Merced Hatchery Monitoring
Cross-Section 2738+90 Surveys
Date of Survey
April 1990 Pre-Construction Topo
Design Elevation (10/90, 9/96, 9/97, 9/00, 7/03)
April 1996 (Pre-Augmentation 96)
July 1997 (Pre-Augmentation 97)
Elevation
296
294
292
290
288
286
284
282
0
50
100
150
200
Distance from Left Bank

Figure A-6



Merced Hatchery Monitoring
Cross-Section 2739+03 Surveys
Date of Survey
April 1990 Pre-Construction Topo
Design Elevation (10/90, 9/96, 9/97, 9/00, 7/03)
November 1995
October 2000 (Post-Augmentation 2000)
July 2002
June 2003 (Pre-Augmentation 03)
October 2003 (Post-Augmentation 03)
Elevation
296
294
292
290
288
286
284
282
0
50
100
150
200
Distance from Left Bank

Figure A-7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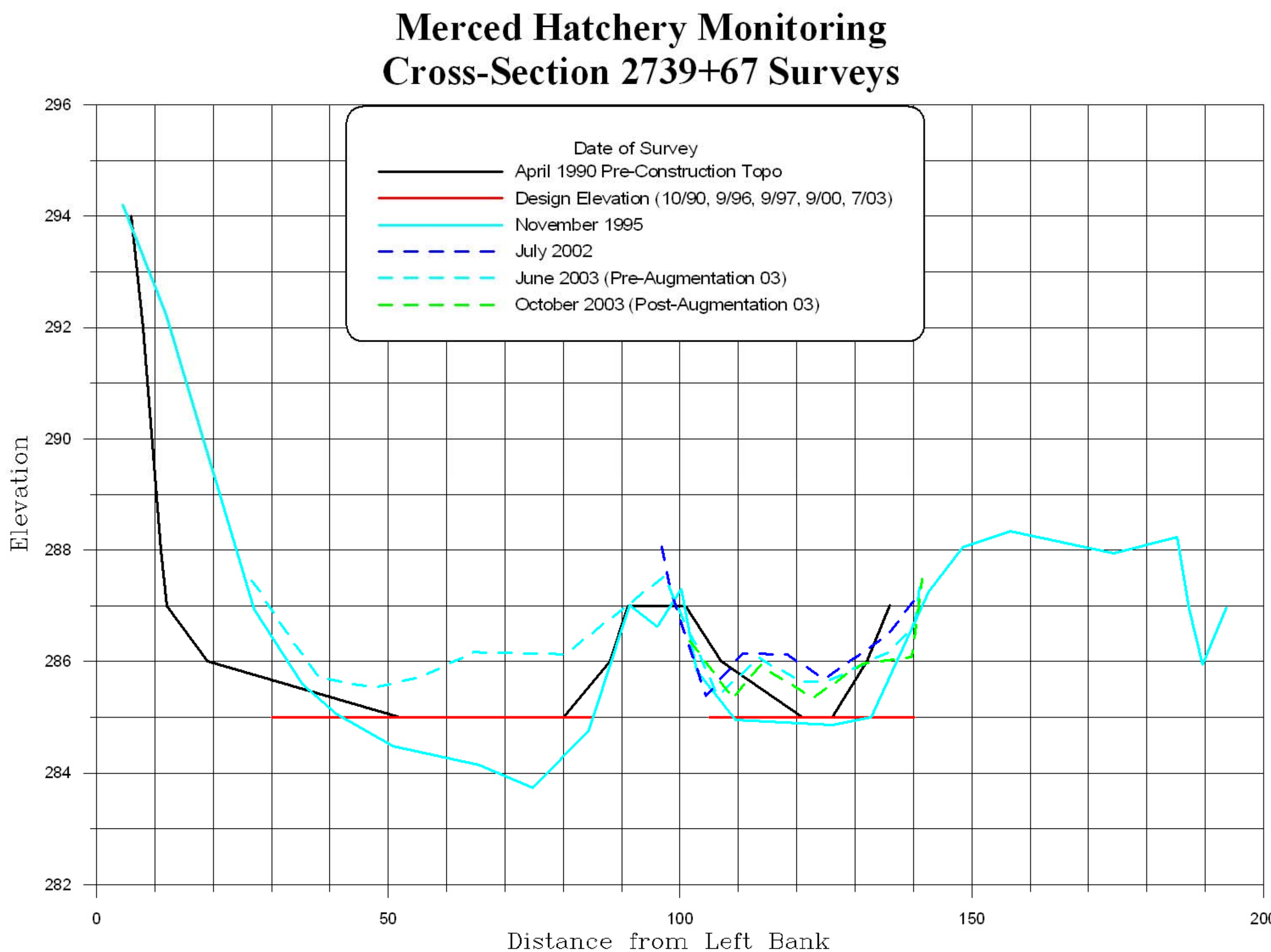
Cross-Section 2739+40 Surveys
Date of Survey
April 1990 Pre-Construction Topo
Design Elevation (10/90, 9/96, 9/97, 9/00, 7/03)
November 1994 (Kondolf, et al.)
April 1996 (Pre-Augmentation 96)
July 1997 (Pre-Augmentation 97)
October 2000 (Post-Augmentation 2000)
July 2002
October 2003 (Post-Augmentation 03)
Elevation
296
294
292
290
288
286
284
282
0
50
100
150
200
Distance from Left Bank

Figure A-8



Merced Hatchery Monitoring
Cross-Section 2739+67 Surveys
Date of Survey
April 1990 Pre-Construction Topo
Design Elevation (10/90, 9/96, 9/97, 9/00, 7/03)
November 1995
July 2002
June 2003 (Pre-Augmentation 03)
October 2003 (Post-Augmentation 03)
Elevation
296
294
292
290
288
286
284
282
0
50
100
150
200
Distance from Left Bank

Figure A-9

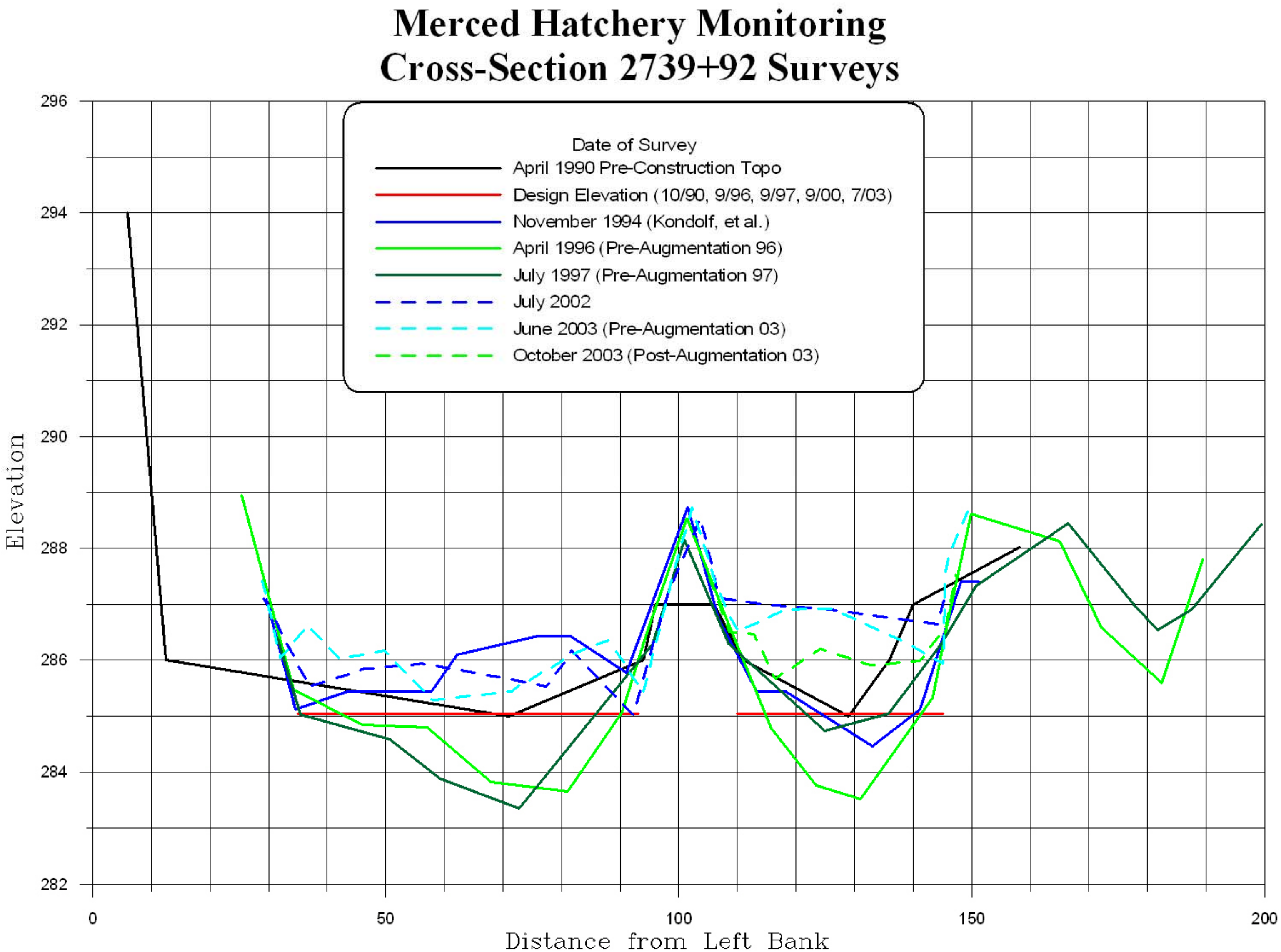
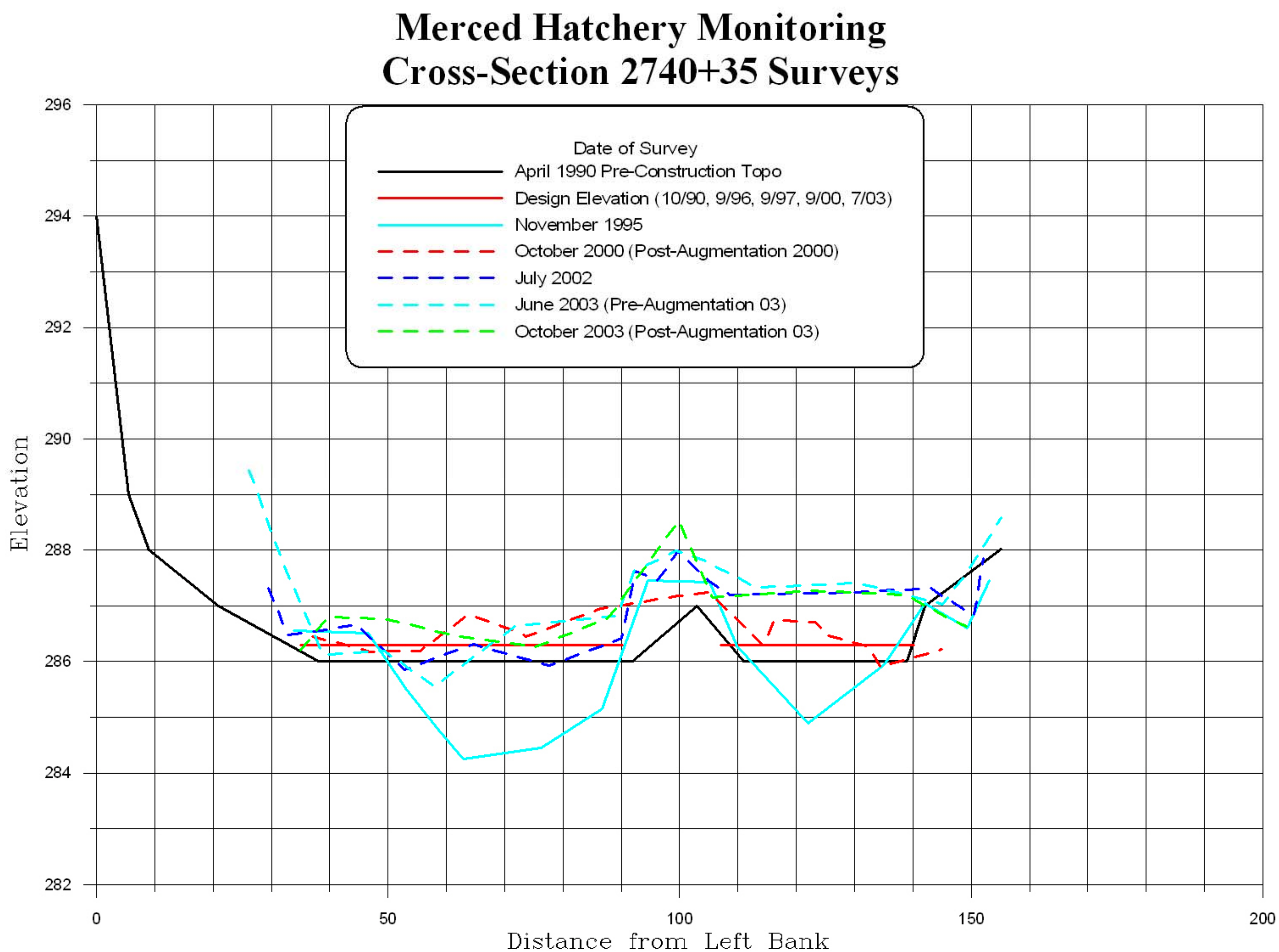
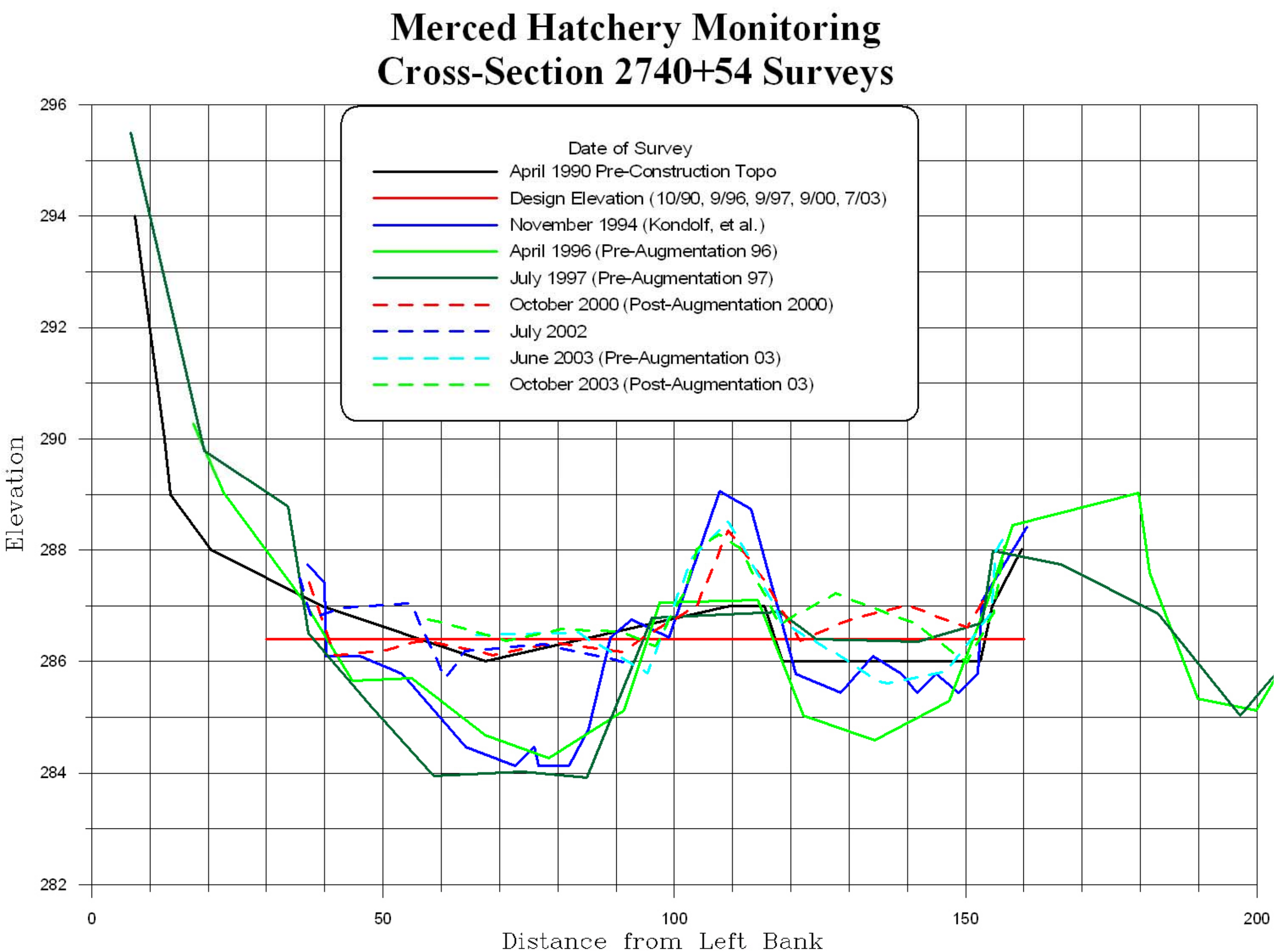

Merced Hatchery Monitoring
Cross-Section 2739+92 Surveys
Date of Survey
April 1990 Pre-Construction Topo
Design Elevation (10/90, 9/96, 9/97, 9/00, 7/03)
November 1994 (Kondolf, et al.)
April 1996 (Pre-Augmentation 96)
July 1997 (Pre-Augmentation 97)
July 2002
June 2003 (Pre-Augmentation 03)
October 2003 (Post-Augmentation 03)
Elevation
296
294
292
290
288
286
284
282
0
50
100
150
200
Distance from Left Bank

Figure A-10



Merced Hatchery Monitoring
Cross-Section 2740+35 Surveys
Date of Survey
April 1990 Pre-Construction Topo
Design Elevation (10/90, 9/96, 9/97, 9/00, 7/03)
November 1995
October 2000 (Post-Augmentation 2000)
July 2002
June 2003 (Pre-Augmentation 03)
October 2003 (Post-Augmentation 03)
Elevation
296
294
292
290
288
286
284
282
0
50
100
150
200
Distance from Left Bank

Figure A-11



Merced Hatchery Monitoring
Cross-Section 2740+54 Surveys
Date of Survey
April 1990 Pre-Construction Topo
Design Elevation (10/90, 9/96, 9/97, 9/00, 7/03)
November 1994 (Kondolf, et al.)
April 1996 (Pre-Augmentation 96)
July 1997 (Pre-Augmentation 97)
October 2000 (Post-Augmentation 2000)
July 2002
June 2003 (Pre-Augmentation 03)
October 2003 (Post-Augmentation 03)
Elevation
296
294
292
290
288
286
284
282
0
50
100
150
200
Distance from Left Bank

Figure A-12

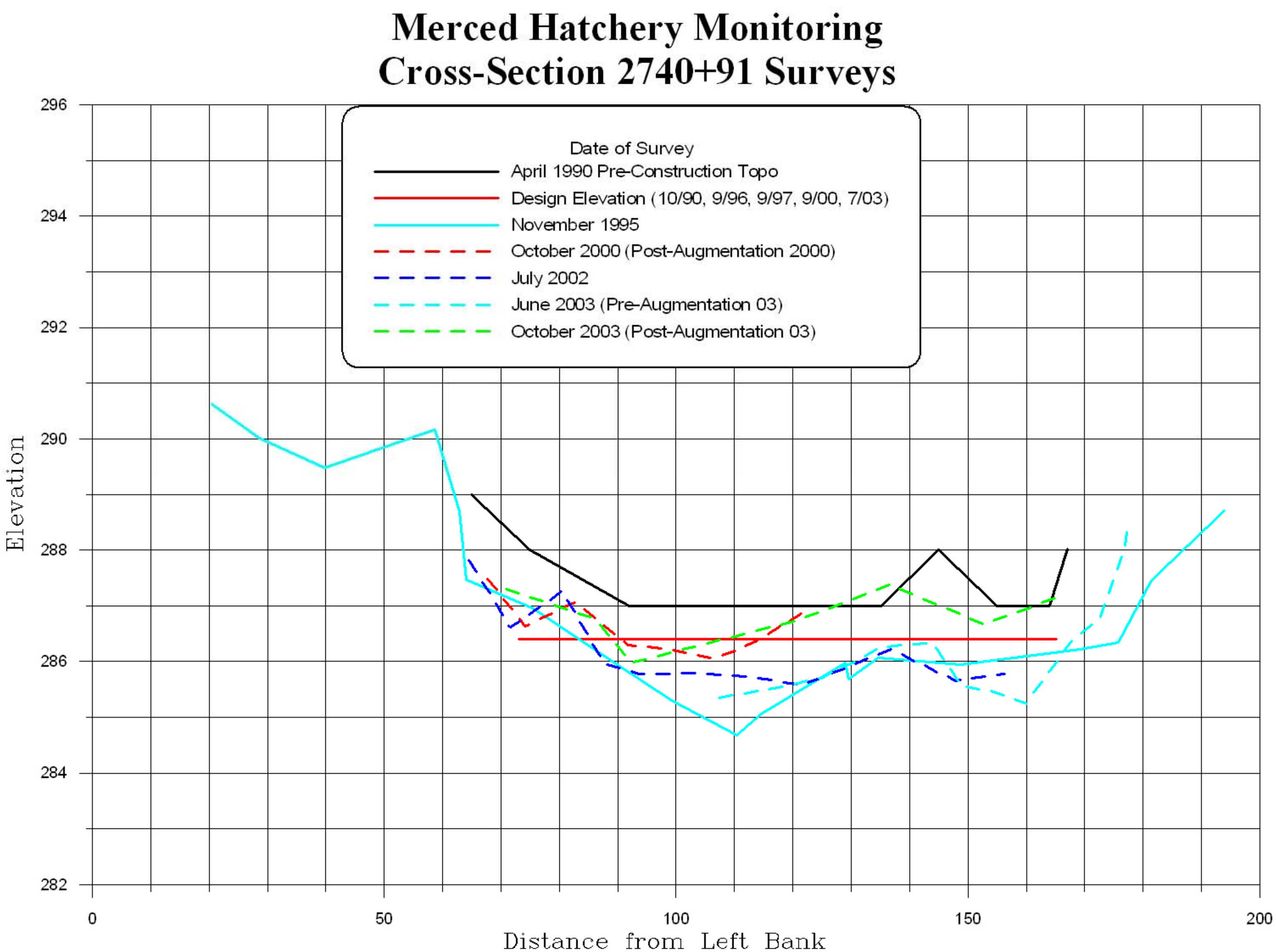

Merced Hatchery Monitoring
Cross-Section 2740+91 Surveys
Date of Survey
April 1990 Pre-Construction Topo
Design Elevation (10/90, 9/96, 9/97, 9/00, 7/03)
November 1995
October 2000 (Post-Augmentation 2000)
July 2002
June 2003 (Pre-Augmentation 03)
October 2003 (Post-Augmentation 03)
Elevation
296
294
292
290
288
286
284
282
0
50
100
150
200
Distance from Left Bank

Figure A-13

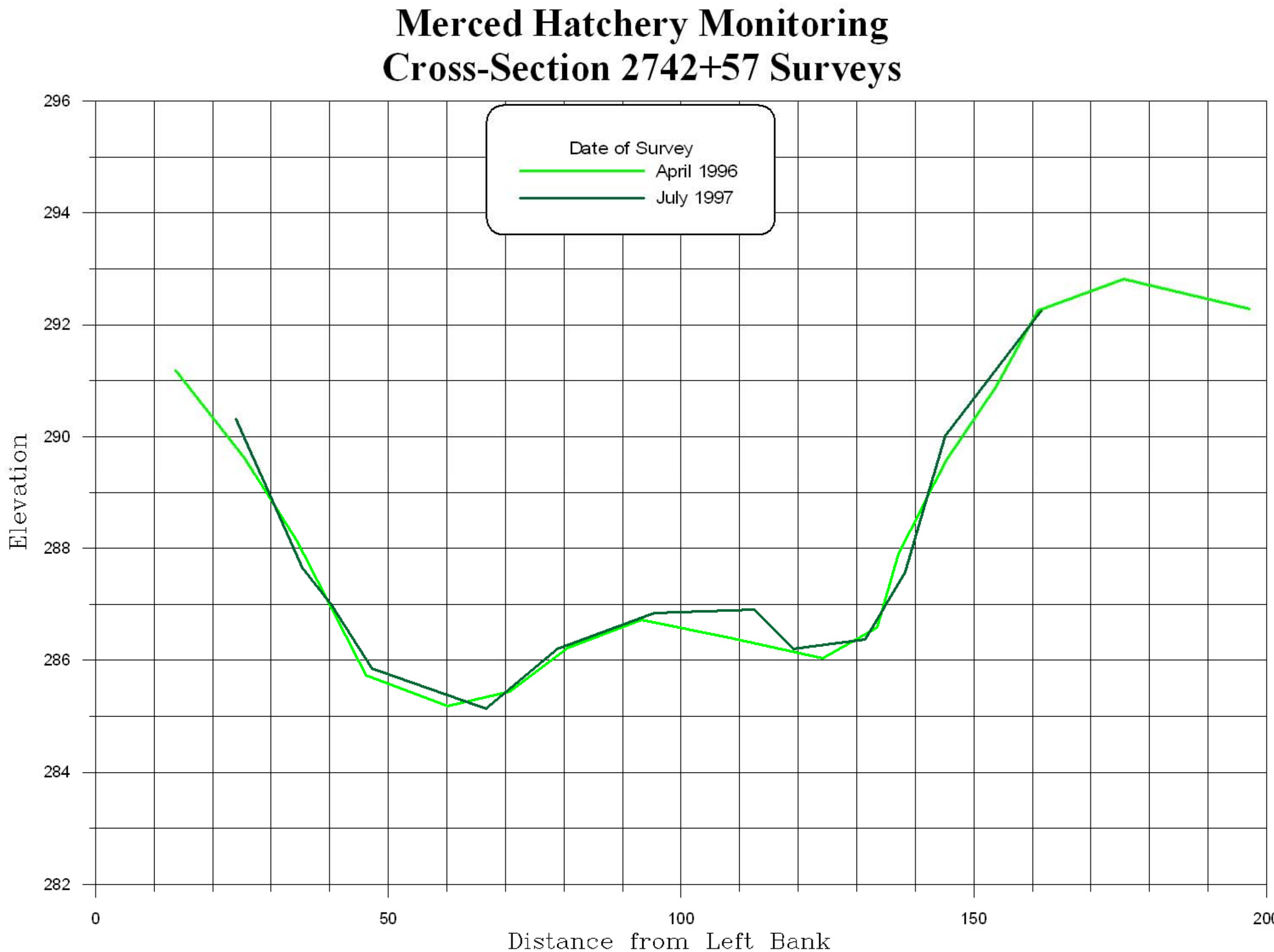

Merced Hatchery Monitoring
Cross-Section 2742+57 Surveys
Date of Survey
April 1996
July 1997
296
294
292
290
288
286
284
282
Elevation
0
50
100
150
200
Distance from Left Bank

Figure A-14

APPENDIX B
Pebble Count Particle Size Distribution Curves

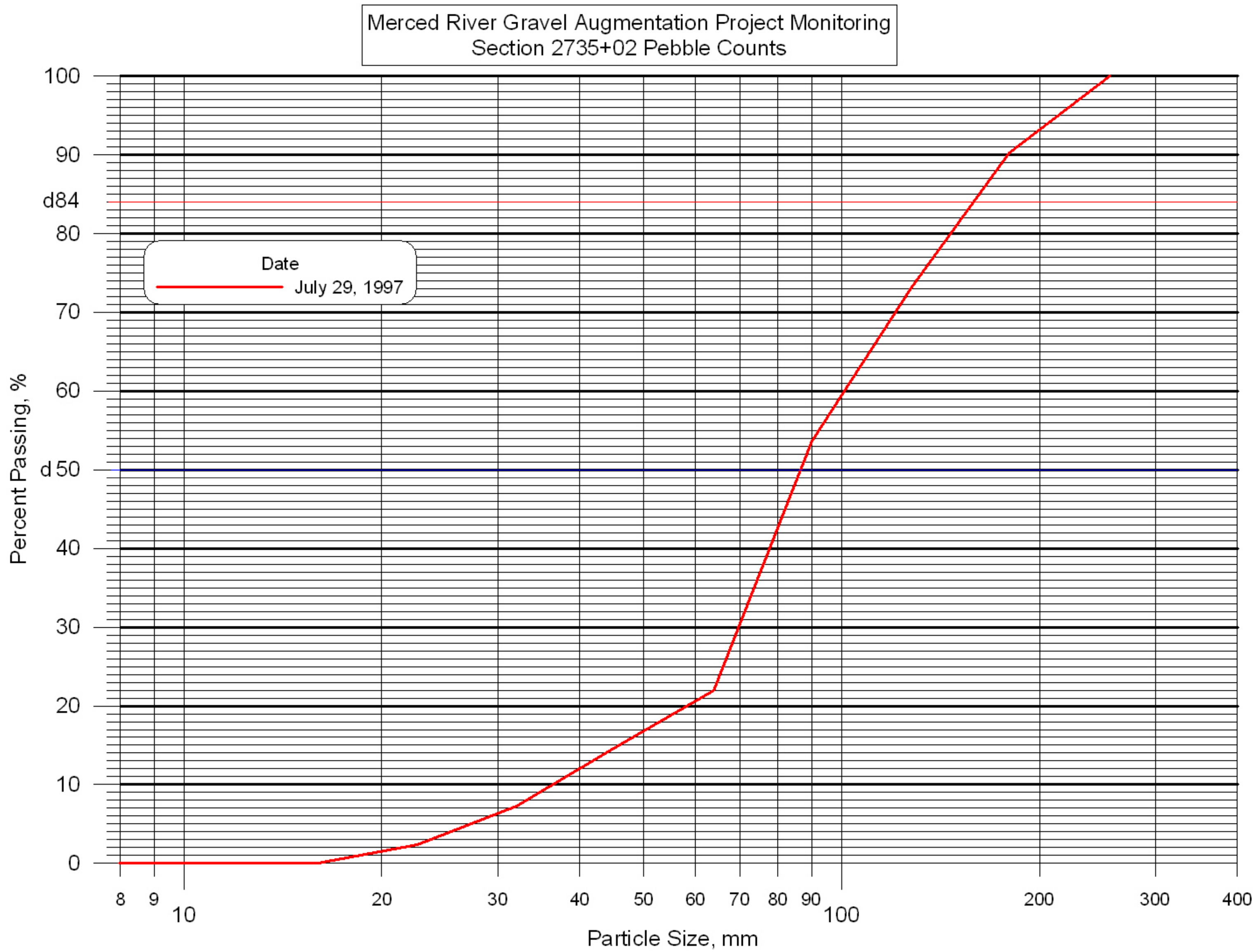

Merced River Gravel Augmentation Project Monitoring
Section 2735+02 Pebble Counts
100
90
d84
80
70
60
d 50
40
30
20
10
0
Percent Passing, %
Date
July 29, 1997
8
9
10
20
30
40
50
60
70
80
90
100
200
300
400
Particle Size, mm

Figure B-1

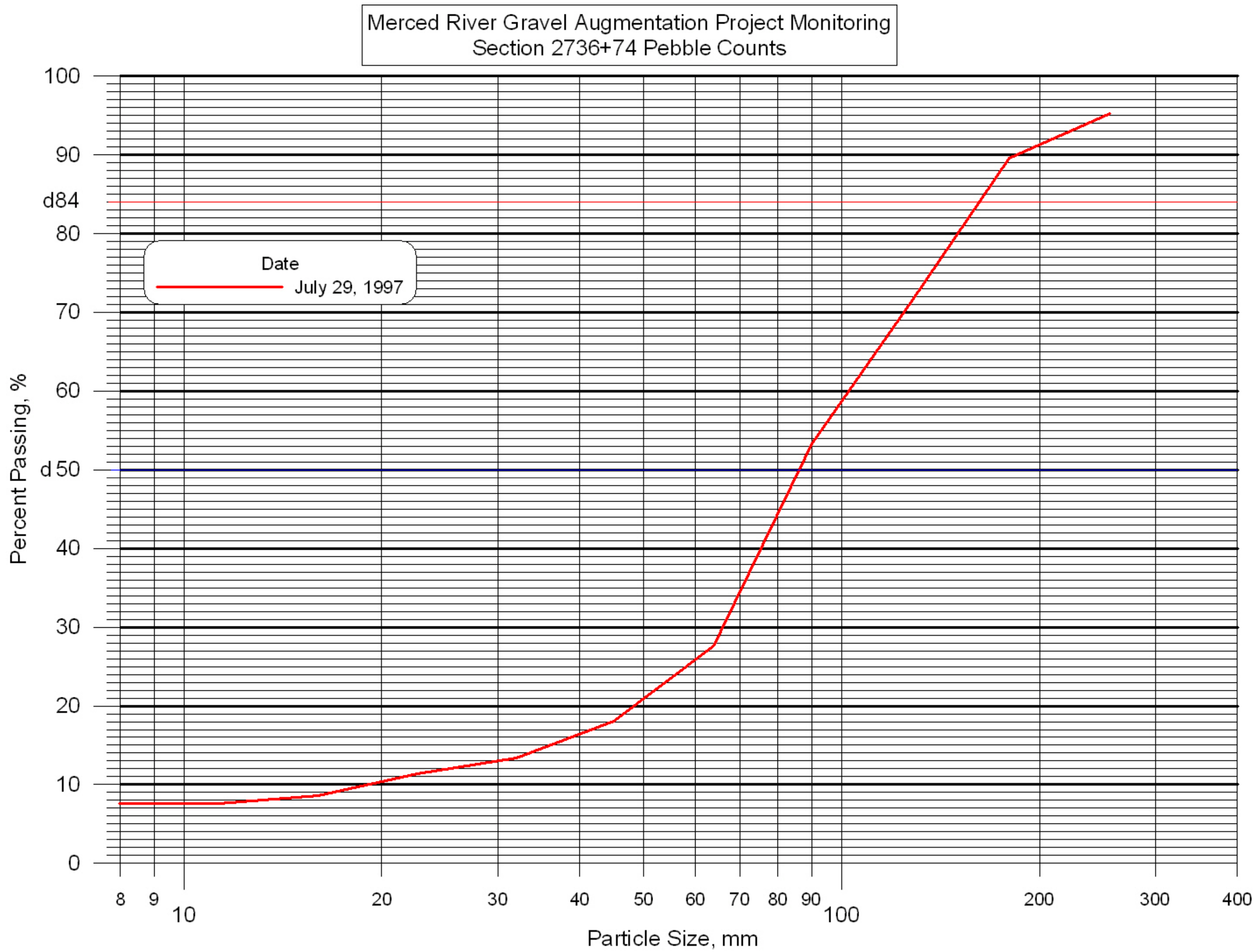
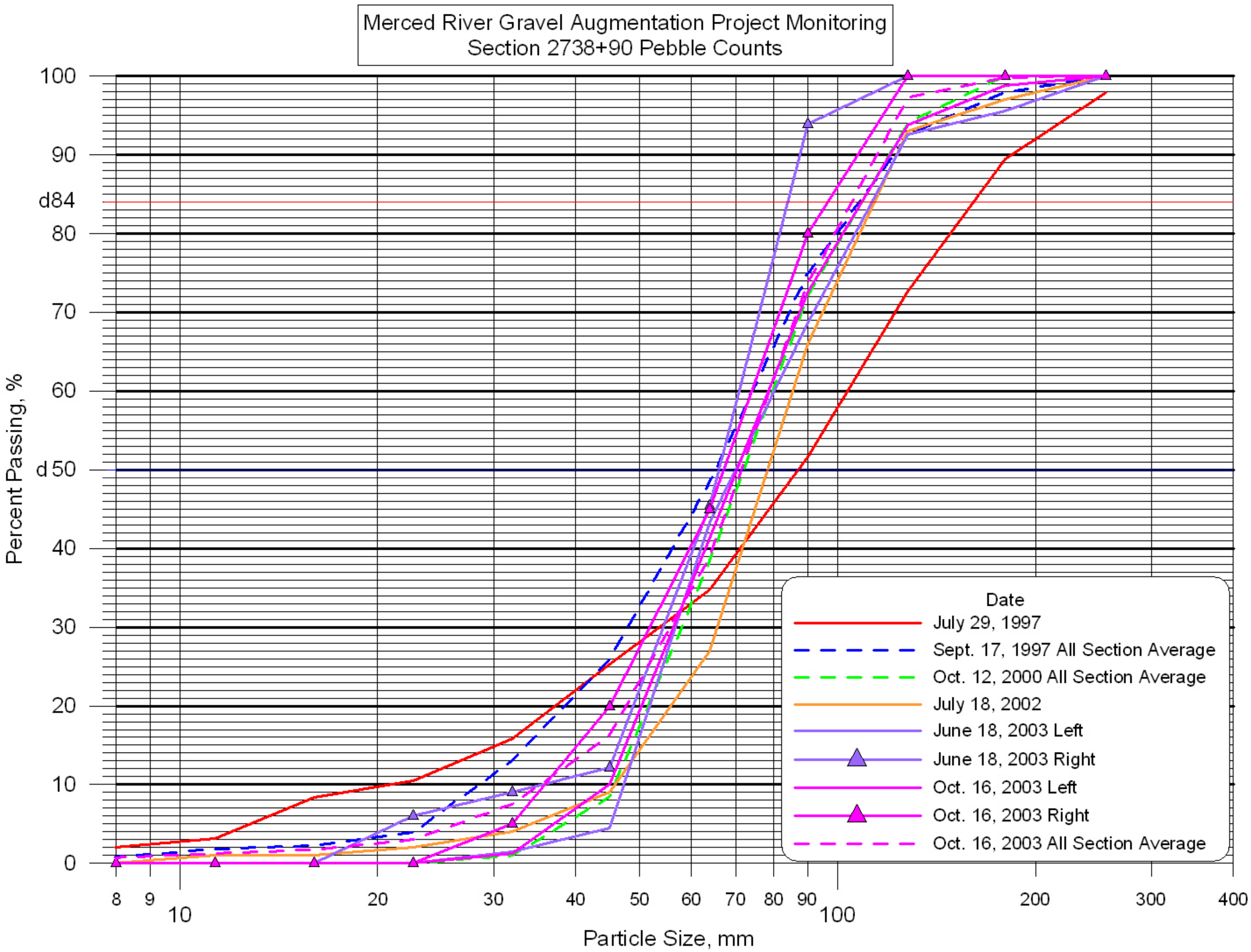
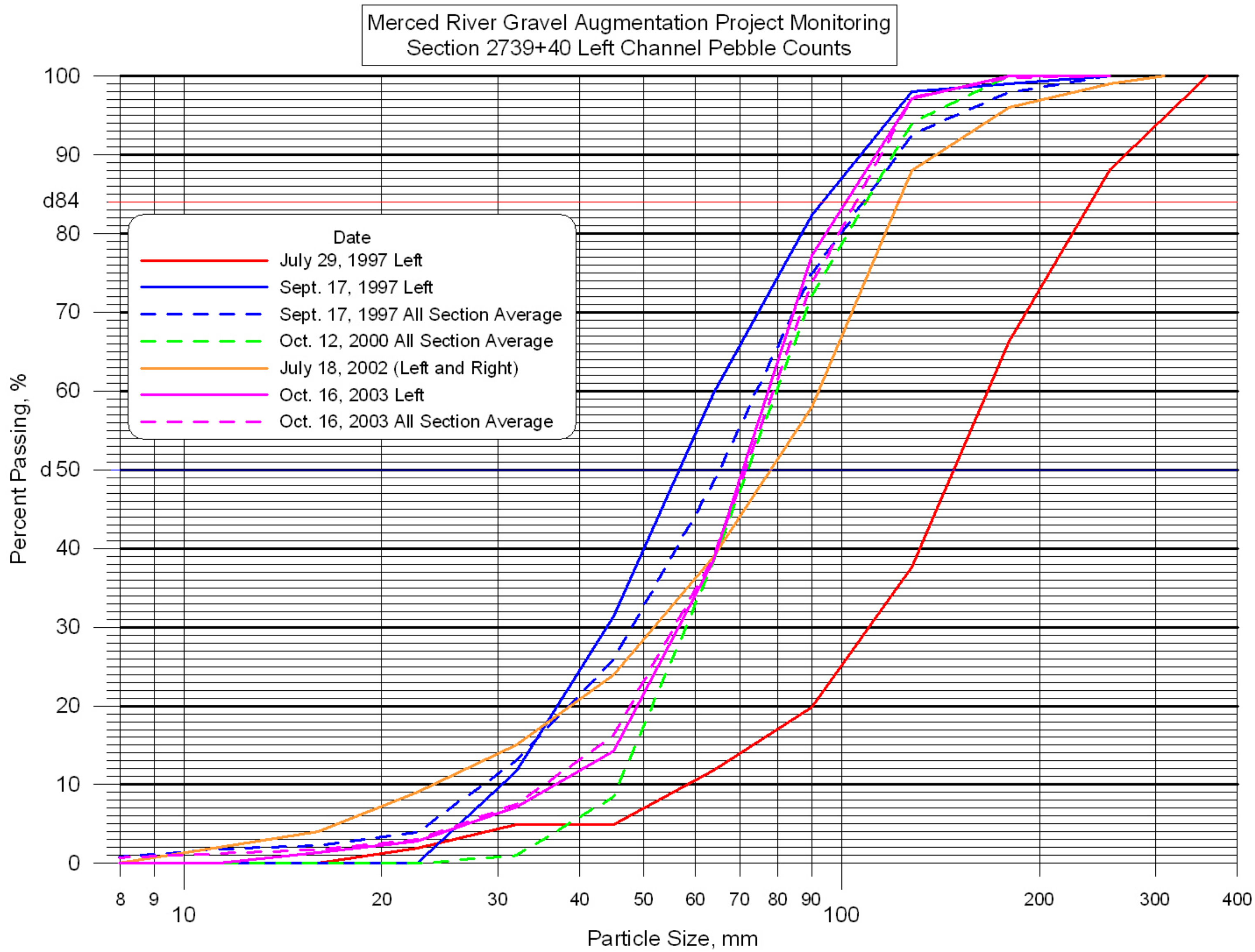

Merced River Gravel Augmentation Project Monitoring
Section 2736+74 Pebble Counts
Date
July 29, 1997
Percent Passing, %
100
90
d84
80
70
60
d 50
40
30
20
10
0
8
9
10
20
30
40
50
60
70
80
90
100
200
300
400
Particle Size, mm

Figure B-2



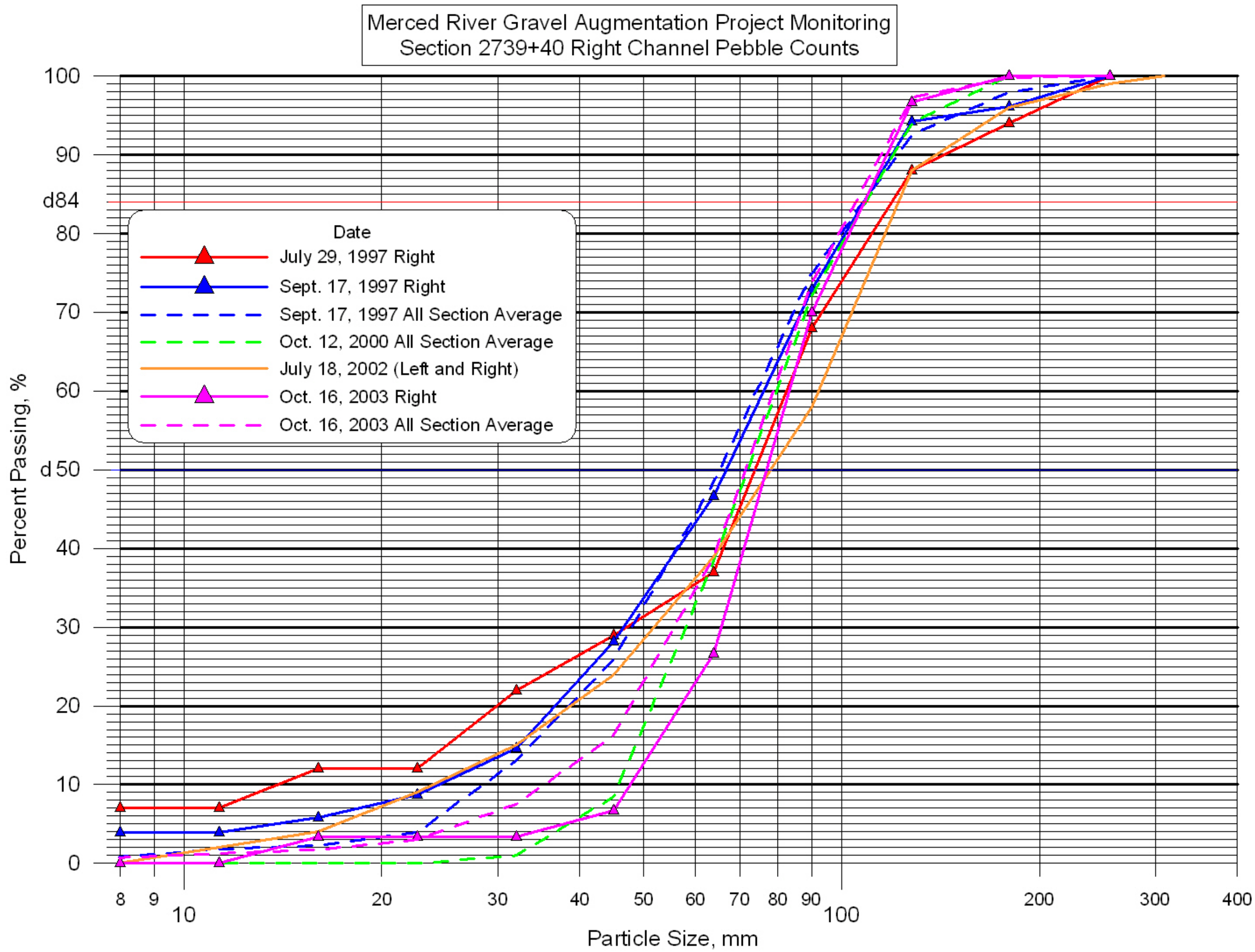
Merced River Gravel Augmentation Project Monitoring
Section 2738+90 Pebble Counts
100
90
d84
80
70
60
d 50
40
30
20
10
0
Percent Passing, %
8
9
10
20
30
40
50
60
70
80
90
100
200
300
400
Particle Size, mm
Date
July 29, 1997
Sept. 17, 1997 All Section Average
Oct. 12, 2000 All Section Average
July 18, 2002
June 18, 2003 Left
June 18, 2003 Right
Oct. 16, 2003 Left
Oct. 16, 2003 Right
Oct. 16, 2003 All Section Average

Figure B-3



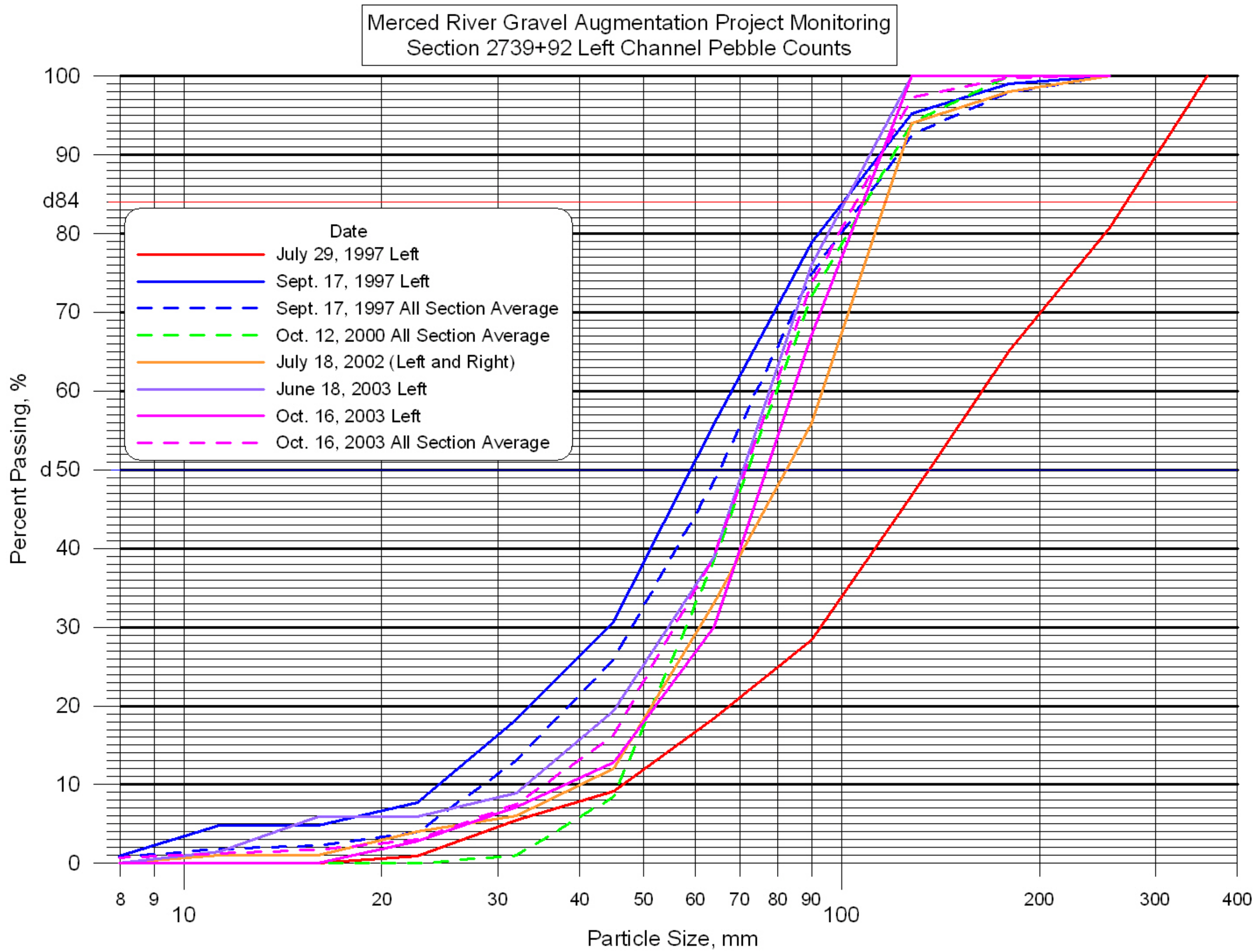
Merced River Gravel Augmentation Project Monitoring
Section 2739+40 Left Channel Pebble Counts
100
90
d84
80
70
60
d 50
40
30
20
10
0
Percent Passing, %
Date
July 29, 1997 Left
Sept. 17, 1997 Left
Sept. 17, 1997 All Section Average
Oct. 12, 2000 All Section Average
July 18, 2002 (Left and Right)
Oct. 16, 2003 Left
Oct. 16, 2003 All Section Average
8
9
10
20
30
40
50
60
70
80
90
100
200
300
400
Particle Size, mm

Figure B-4



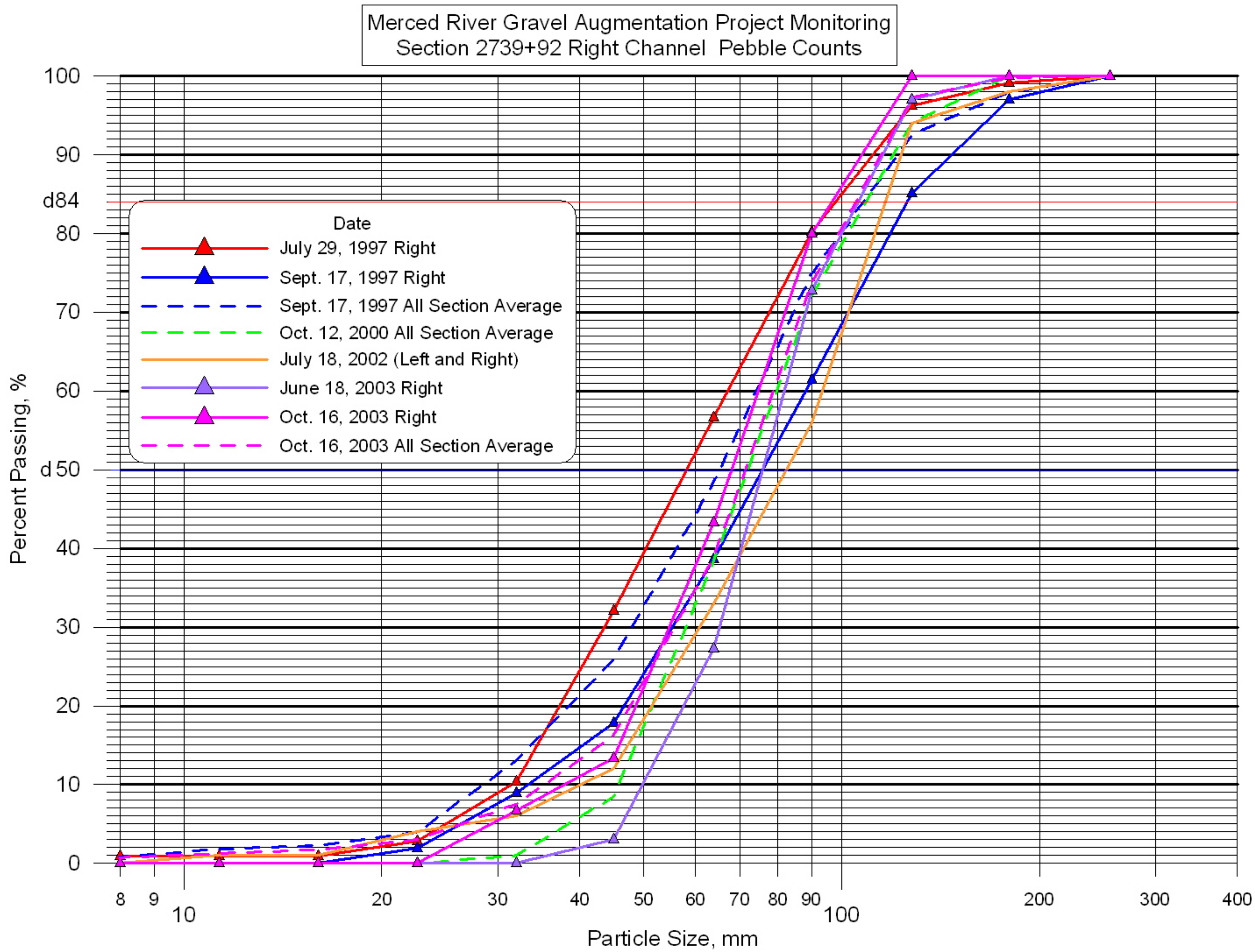
Merced River Gravel Augmentation Project Monitoring
Section 2739+40 Right Channel Pebble Counts
Percent Passing, %
Particle Size, mm
100
90
d84
80
70
60
d 50
40
30
20
10
0
8
9
10
20
30
40
50
60
70
80
90
100
200
300
400
Date
July 29, 1997 Right
Sept. 17, 1997 Right
Sept. 17, 1997 All Section Average
Oct. 12, 2000 All Section Average
July 18, 2002 (Left and Right)
Oct. 16, 2003 Right
Oct. 16, 2003 All Section Average

Figure B-5



Merced River Gravel Augmentation Project Monitoring
Section 2739+92 Left Channel Pebble Counts
Percent Passing, %
100
90
d84
80
70
60
d 50
40
30
20
10
0
Date
July 29, 1997 Left
Sept. 17, 1997 Left
Sept. 17, 1997 All Section Average
Oct. 12, 2000 All Section Average
July 18, 2002 (Left and Right)
June 18, 2003 Left
Oct. 16, 2003 Left
Oct. 16, 2003 All Section Average
8
9
10
20
30
40
50
60
70
80
90
100
200
300
400
Particle Size, mm

Figure B-6



Merced River Gravel Augmentation Project Monitoring
Section 2739+92 Right Channel Pebble Counts
Percent Passing, %
100
90
d84
80
70
60
d 50
40
30
20
10
0
Date
July 29, 1997 Right
Sept. 17, 1997 Right
Sept. 17, 1997 All Section Average
Oct. 12, 2000 All Section Average
July 18, 2002 (Left and Right)
June 18, 2003 Right
Oct. 16, 2003 Right
Oct. 16, 2003 All Section Average
8
9
10
20
30
40
50
60
70
80
90
100
200
300
400
Particle Size, mm

Figure B-7

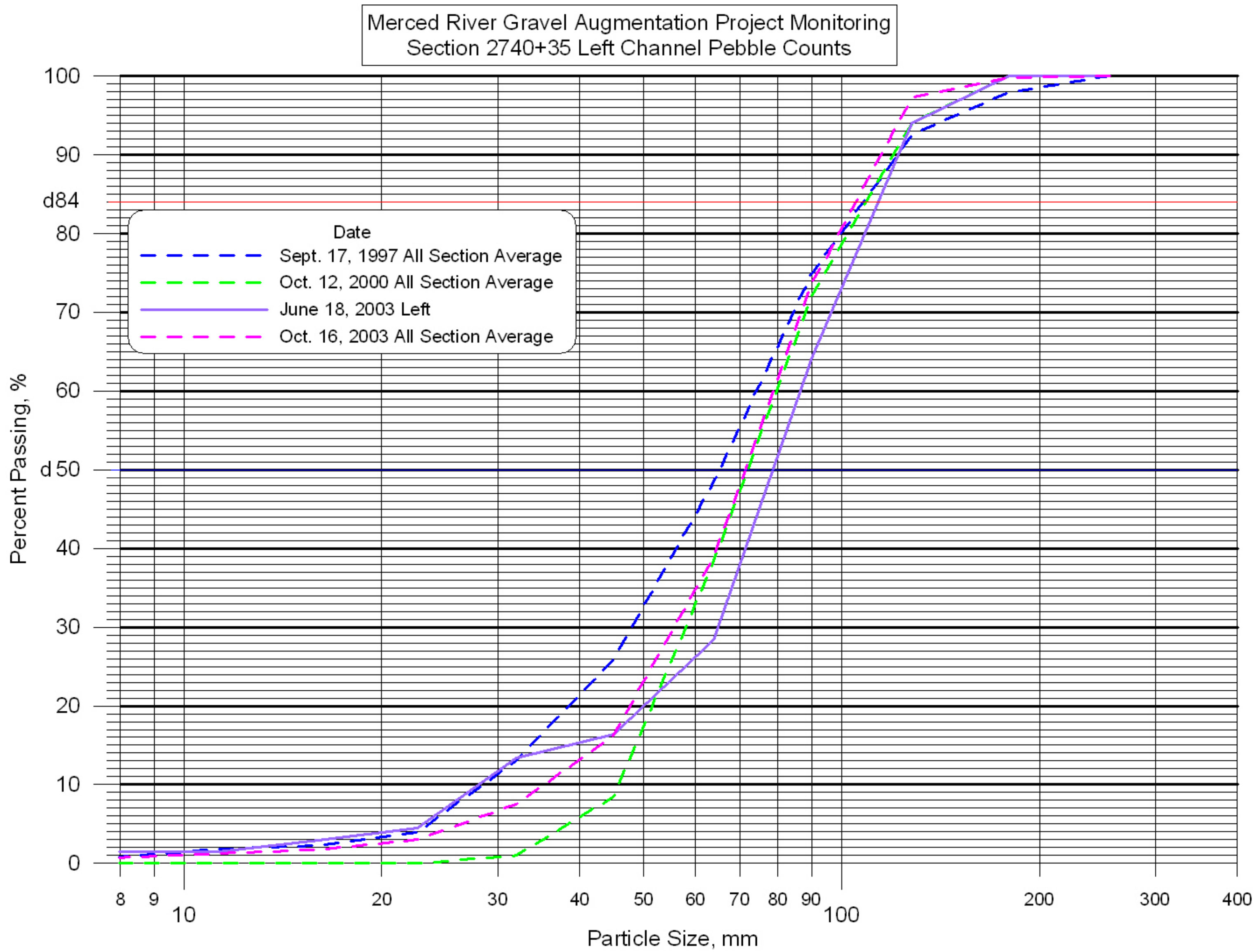
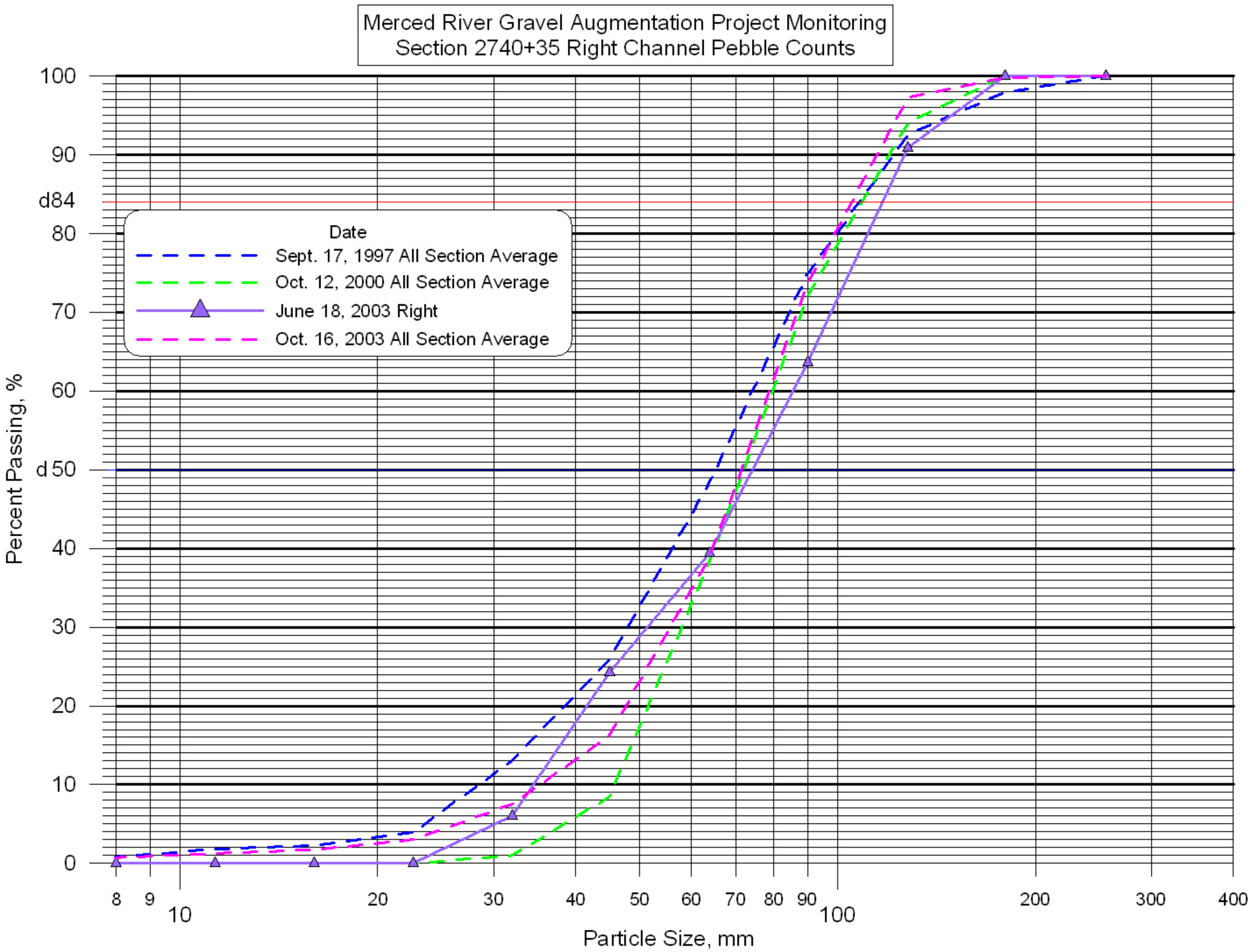

Merced River Gravel Augmentation Project Monitoring
Section 2740+35 Left Channel Pebble Counts
Date
Sept. 17, 1997 All Section Average
Oct. 12, 2000 All Section Average
June 18, 2003 Left
Oct. 16, 2003 All Section Average
Percent Passing, %
100
90
d84
80
70
60
d 50
40
30
20
10
0
8
9
10
20
30
40
50
60
70
80
90
100
200
300
400
Particle Size, mm

Figure B-8



Merced River Gravel Augmentation Project Monitoring
Section 2740+35 Right Channel Pebble Counts
Date
Sept. 17, 1997 All Section Average
Oct. 12, 2000 All Section Average
June 18, 2003 Right
Oct. 16, 2003 All Section Average
Percent Passing, %
100
90
d84
80
70
60
d 50
40
30
20
10
0
8
9
10
20
30
40
50
60
70
80
90
100
200
300
400
Particle Size, mm

Figure B-9

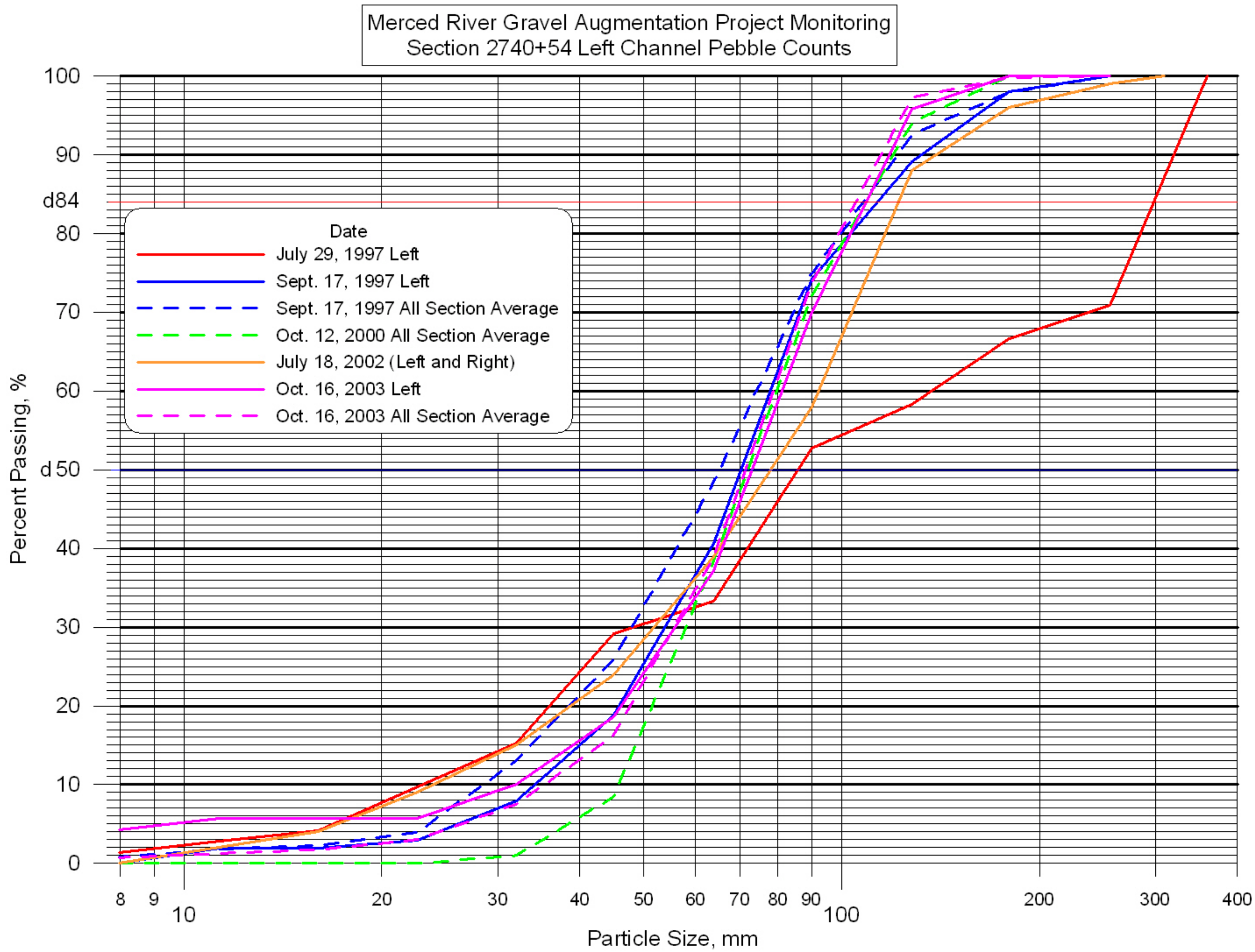
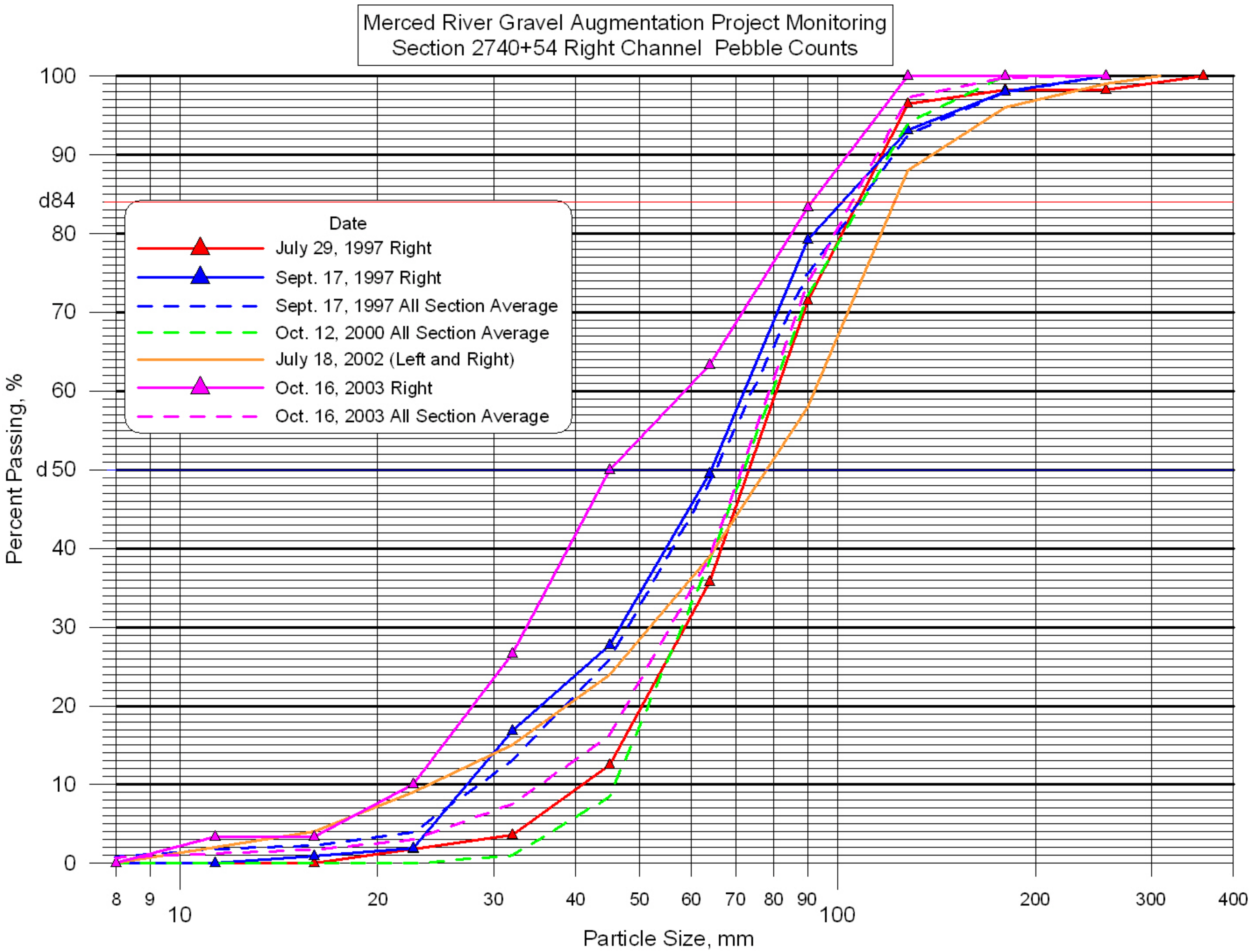

Merced River Gravel Augmentation Project Monitoring
Section 2740+54 Left Channel Pebble Counts
Date
July 29, 1997 Left
Sept. 17, 1997 Left
Sept. 17, 1997 All Section Average
Oct. 12, 2000 All Section Average
July 18, 2002 (Left and Right)
Oct. 16, 2003 Left
Oct. 16, 2003 All Section Average
Percent Passing, %
100
90
d84
80
70
60
d 50
40
30
20
10
0
8
9
10
20
30
40
50
60
70
80
90
100
200
300
400
Particle Size, mm

Figure B-10



Merced River Gravel Augmentation Project Monitoring
Section 2740+54 Right Channel Pebble Counts
Date
July 29, 1997 Right
Sept. 17, 1997 Right
Sept. 17, 1997 All Section Average
Oct. 12, 2000 All Section Average
July 18, 2002 (Left and Right)
Oct. 16, 2003 Right
Oct. 16, 2003 All Section Average
Percent Passing, %
100
90
d84
80
70
60
d 50
40
30
20
10
0
8
9
10
20
30
40
50
60
70
80
90
100
200
300
400
Particle Size, mm

Figure B-11

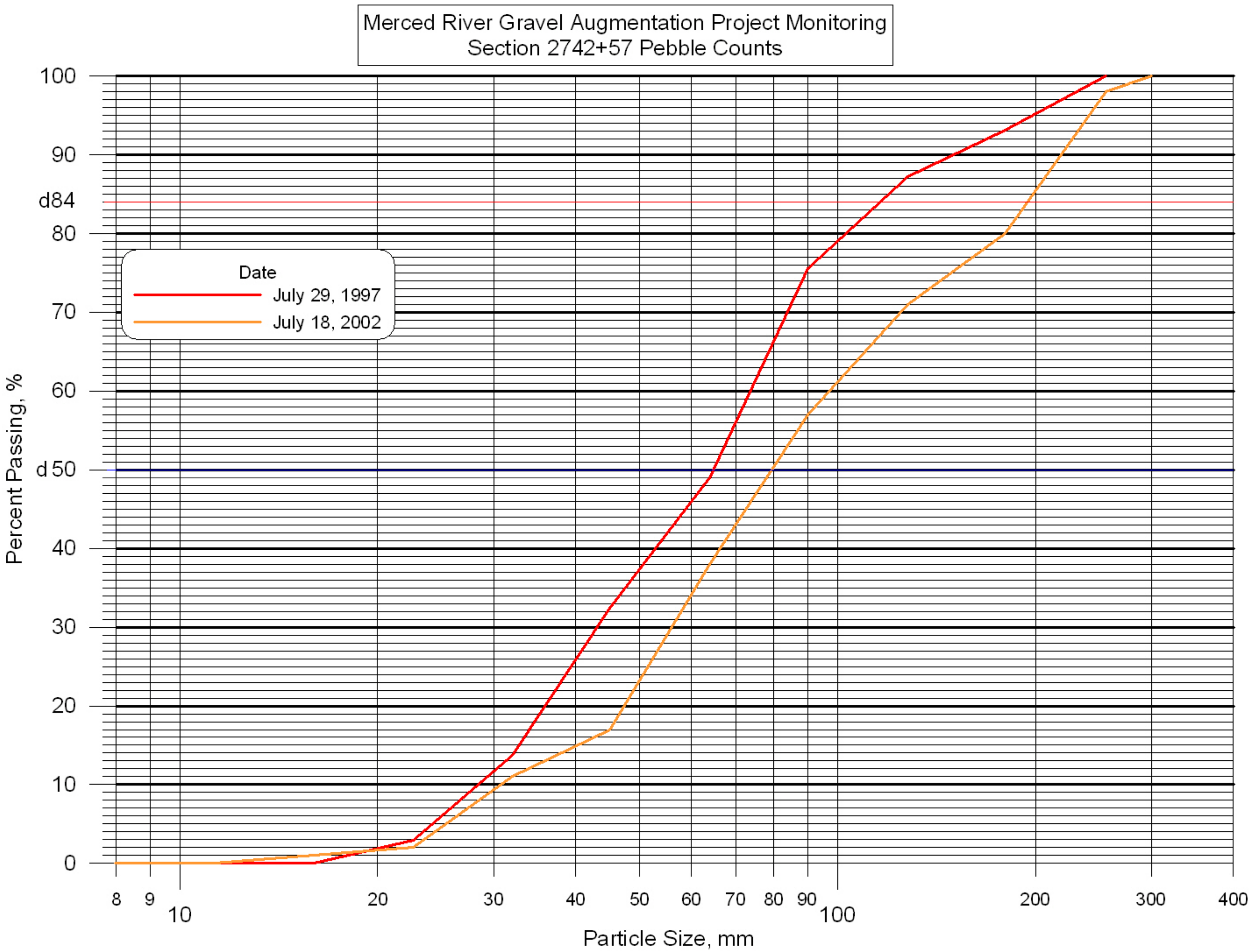

Merced River Gravel Augmentation Project Monitoring
Section 2742+57 Pebble Counts
Date
July 29, 1997
July 18, 2002
Percent Passing, %
100
90
d84
80
70
60
d 50
40
30
20
10
0
8
9
10
20
30
40
50
60
70
80
90
100
200
300
400
Particle Size, mm

Figure B-12

APPENDIX C
Pebble Count Particle Sizes vs. Time

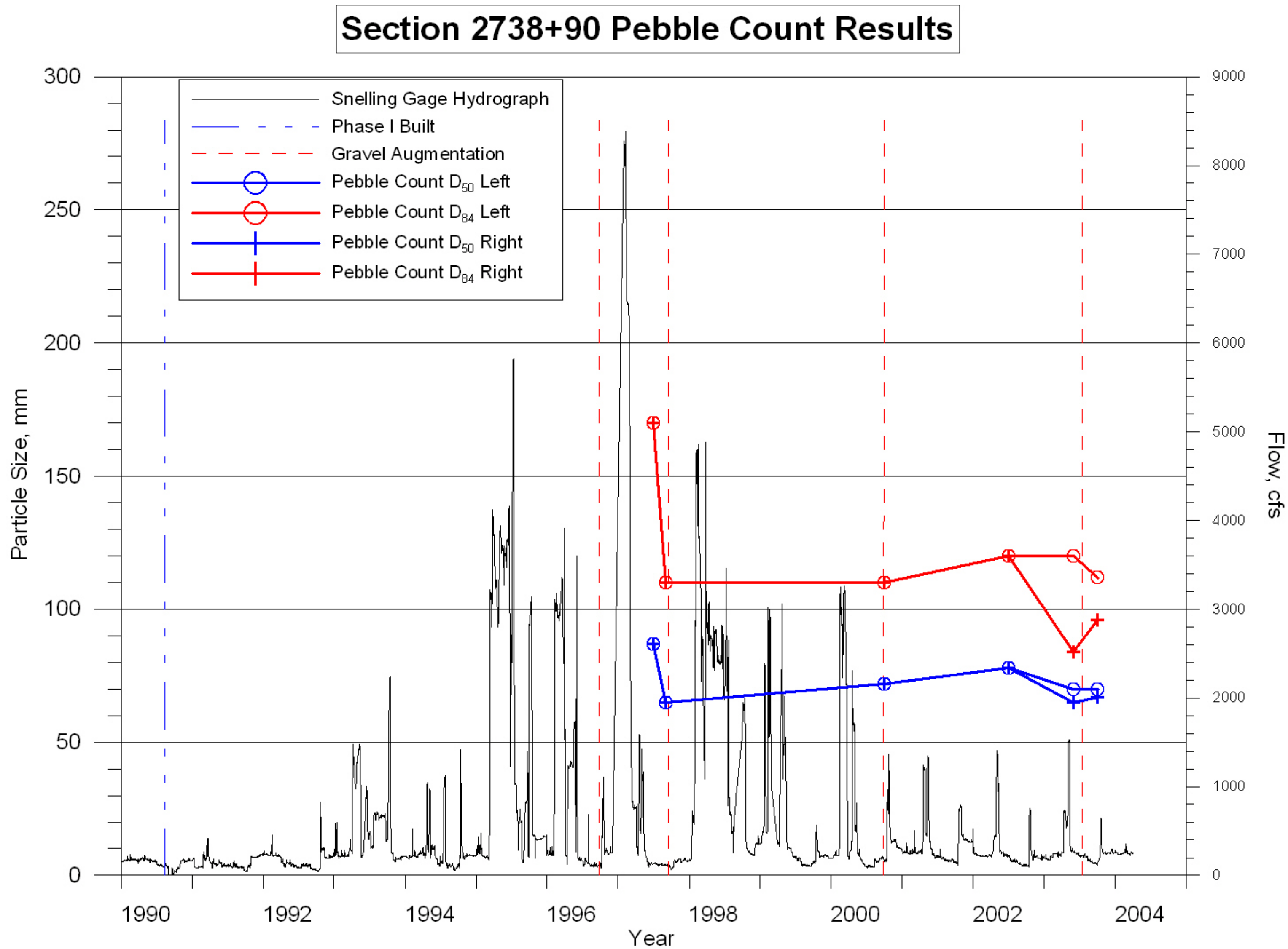
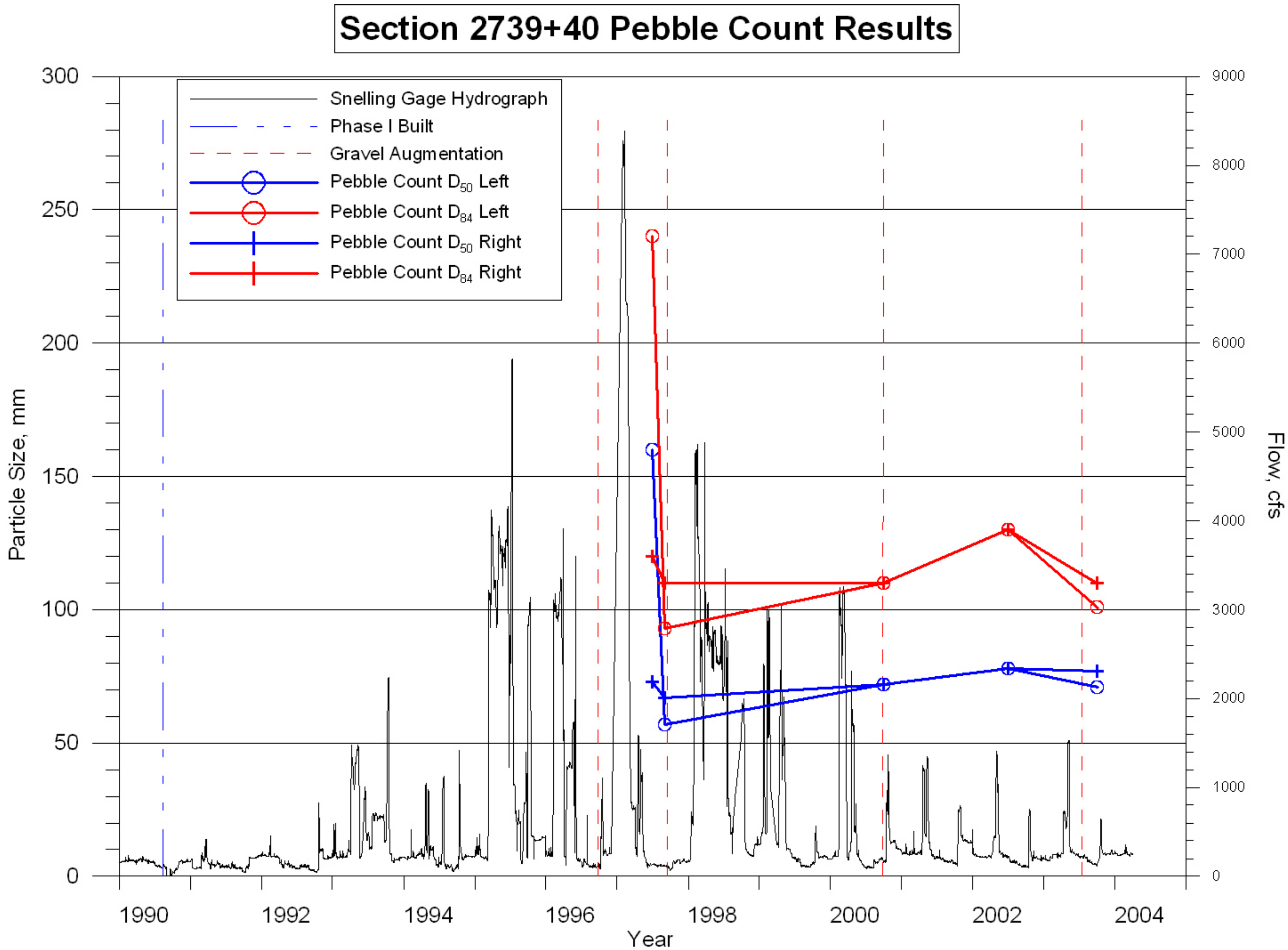

Section 2738+90 Pebble Count Results
Snelling Gage Hydrograph
Phase I Built
Gravel Augmentation
Pebble Count D50 Left
Pebble Count D84 Left
Pebble Count D50 Right
Pebble Count D84 Right
Particle Size, mm
Flow, cfs
Year
0
50
100
150
200
250
300
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
1990
1992
1994
1996
1998
2000
2002
2004

Figure C-1



Section 2739+40 Pebble Count Results
Snelling Gage Hydrograph
Phase I Built
Gravel Augmentation
Pebble Count D50 Left
Pebble Count D84 Left
Pebble Count D50 Right
Pebble Count D84 Right
Particle Size, mm
Flow, cfs
Year
0
50
100
150
200
250
300
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
1990
1992
1994
1996
1998
2000
2002
2004

Figure C-2

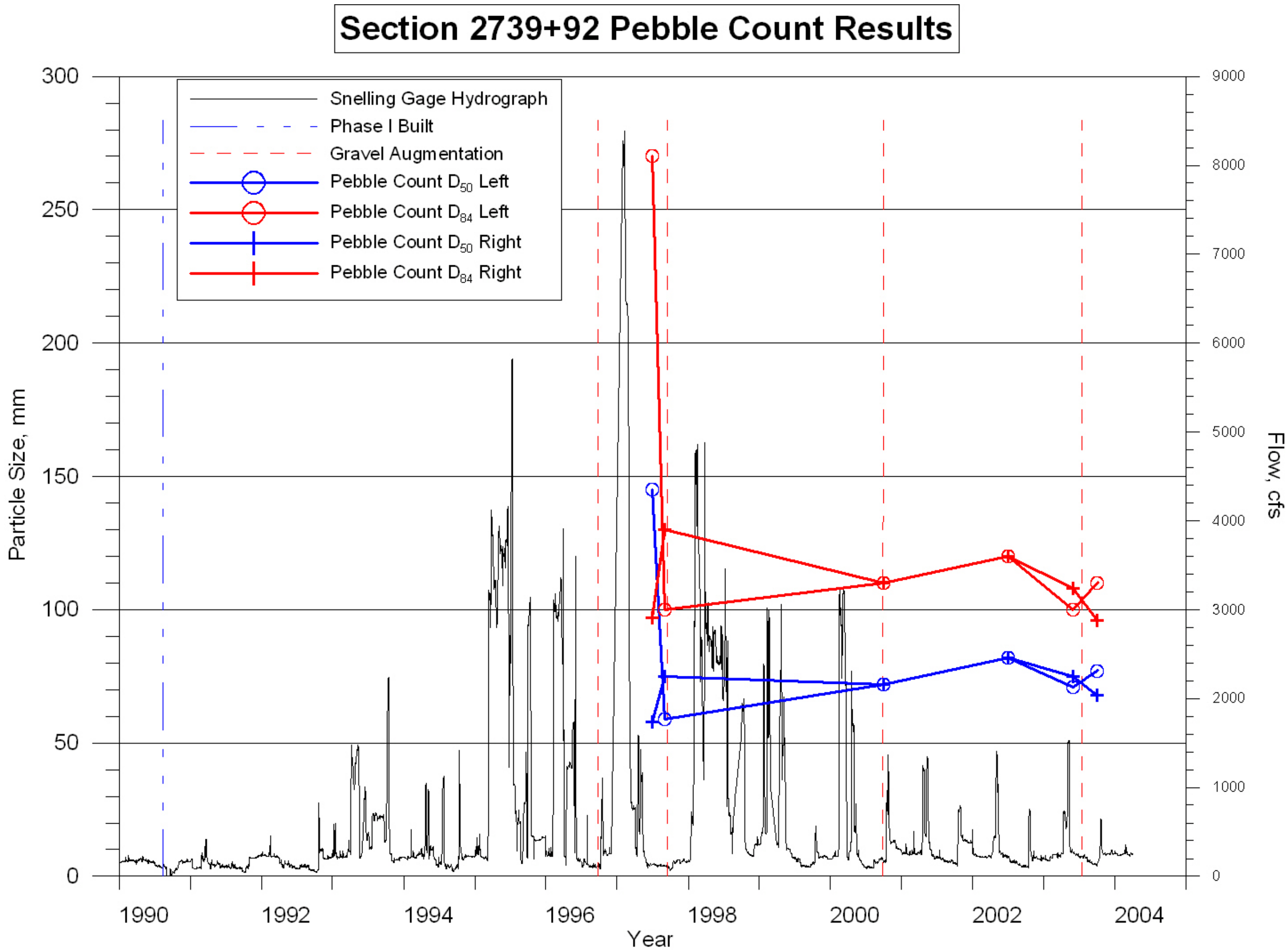

Section 2739+92 Pebble Count Results
Snelling Gage Hydrograph
Phase I Built
Gravel Augmentation
Pebble Count D50 Left
Pebble Count D84 Left
Pebble Count D50 Right
Pebble Count D84 Right
Particle Size, mm
Flow, cfs
Year
300
250
200
150
100
50
0
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
1990
1992
1994
1996
1998
2000
2002
2004

Figure C-3

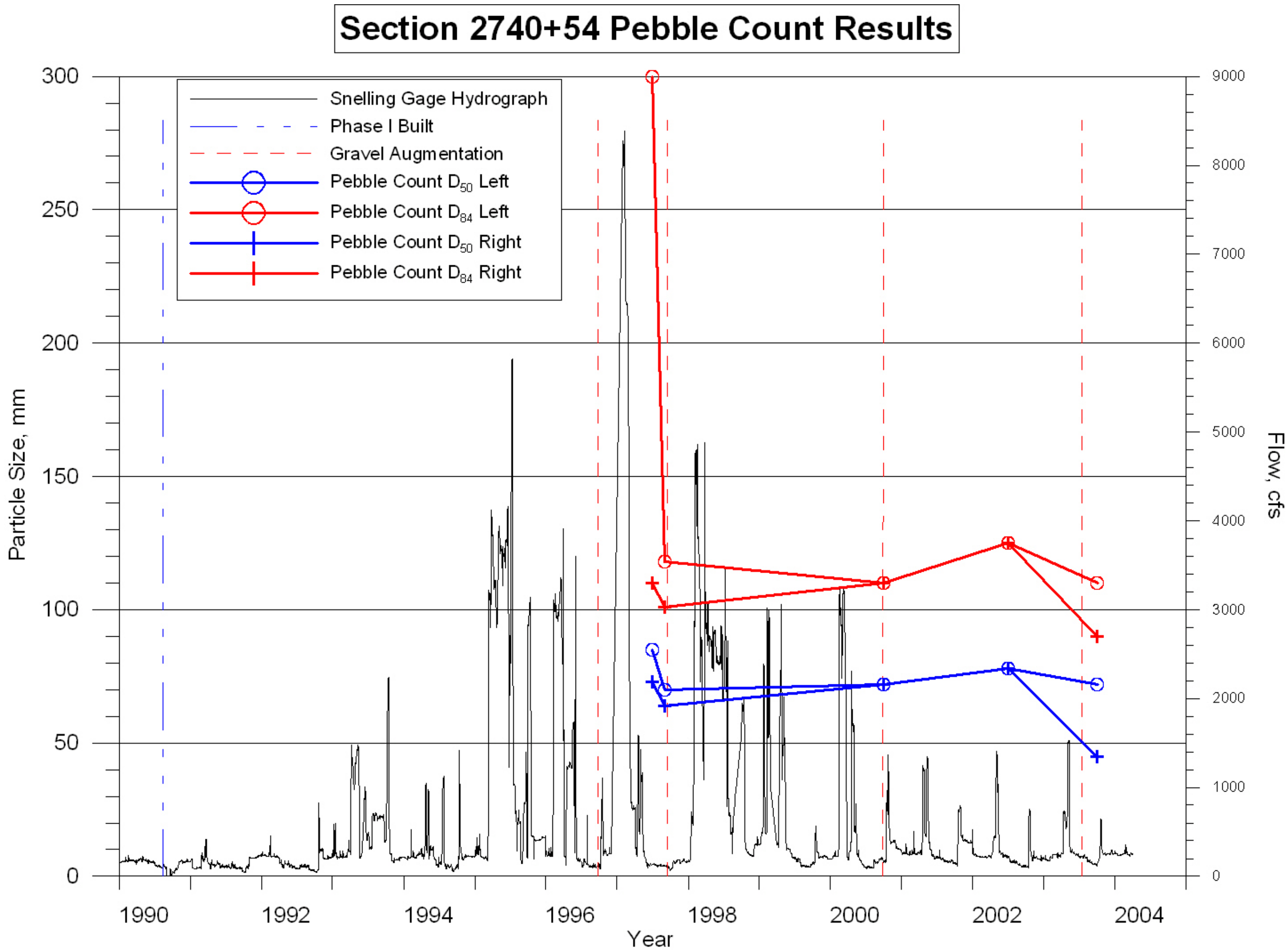
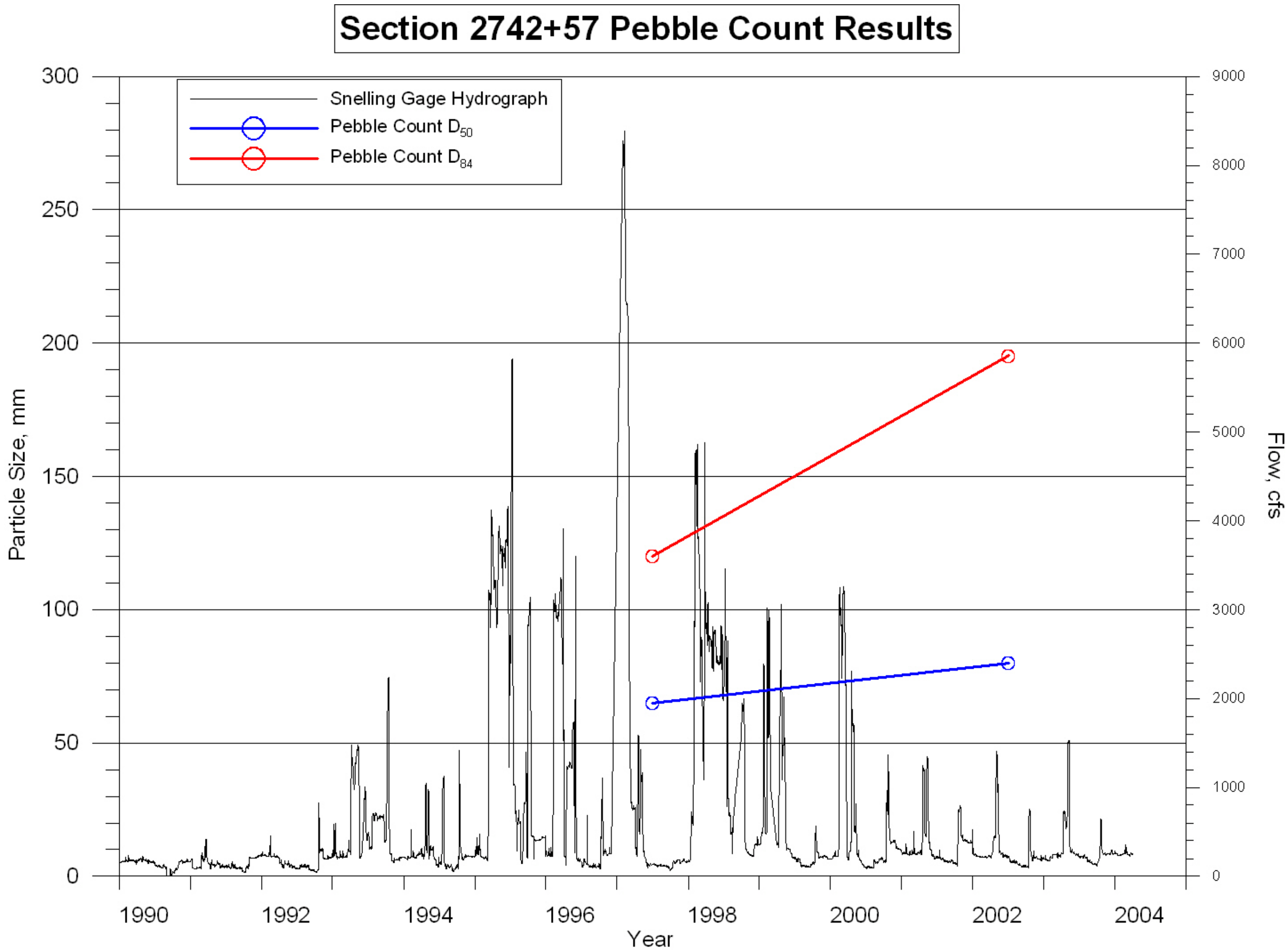

Section 2740+54 Pebble Count Results
Snelling Gage Hydrograph
Phase I Built
Gravel Augmentation
Pebble Count D50 Left
Pebble Count D84 Left
Pebble Count D50 Right
Pebble Count D84 Right
Particle Size, mm
Flow, cfs
Year
0
50
100
150
200
250
300
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
1990
1992
1994
1996
1998
2000
2002
2004

Figure C-4



Section 2742+57 Pebble Count Results
Snelling Gage Hydrograph
Pebble Count D_{50}
Pebble Count D_{84}
Particle Size, mm
Flow, cfs
Year
300
250
200
150
100
50
0
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
1990
1992
1994
1996
1998
2000
2002
2004

Figure C-5